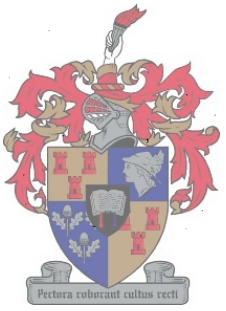

PROCESS CONTROL OF CHEMICALS IN FIBRE FURNISHES

by

ERIC JACQUES DURGUEIL

DISSERTATION APPROVED FOR THE DEGREE OF DOCTOR IN PHILOSOPHY (WOOD SCIENCE) in the DEPARTMENT of WOOD SCIENCE, UNIVERSITY of STELLENBOSCH.

Promotor: Professor G.F.R. GERISCHER

December 1994

DECLARATION

I, the undersigned hereby declare that the work contained in this thesis is my own original work and has not to my knowledge previously in it's entirety or in part been submitted at any university for a degree.

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IN FIBRE FURNISHES

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All testing has been carried out according to TAPPI Standards and Standard Methods for laboratory measurement, "Standard Method for the Examination of Water and Wastewater" (15th edition, 1980, American Public Health Association, Washington DC).

NOMENCLATURE

L/F	: long fibre chemical pulp	
σ	: sigma - standard deviation	
CSF	: Canadian Standard Freeness	
F	: flowmeter	
Vm	: measurement channel signal	Kajaani units
Vref	: reference channel signal	Kajaani units
Vcs	: output signal	Kajaani units
K	: coefficient - equation 4	-
C	: total sample consistency	%
Total Ash	: ash content of sample tested	ppm
Ash	: ash content as a percentage of solids present	%
TMP	: thermomechanical pulp	
GWD	: groundwood pulp	

DEFINITION:

Coagulant : low molecular weight polymer added to the furnish to reduce the repellent forces between the particles in suspension.

Flocculant: : high molecular weight polymer added to the furnish to form a bridge between the neutralized particles to produce discrete agglomerates (flocs).

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PROCESS CONTROL OF CHEMICALS IN FIBRE FURNISHES

ABSTRACT

In a competitive and environmentally concerned business atmosphere, the role of wet end chemistry has become extremely important to a paper mill's profitability and long term viability. In the past decade, understanding of the papermaking chemistry has improved and sensors for measurement of the various variables on-line have been developed. Some of these variables are reviewed as well as the instruments which have been evaluated or developed for on-line measurement during this investigation. Process control loops to maintain control over the wet end chemistry during stock preparation are presented as well as an overall strategy to combine all the control variables. The primary thrust behind the control of the chemicals added is to minimise process variability and improve product uniformity as illustrated in this investigation. A reduction in chemical cost and paper losses coupled with improved customer satisfaction are some of the benefits obtained. More work is still required to fully master the multiple interactions and changing states of wet end chemistry and this will be attained with the improvement of existing or development of new on-line sensors.

PROSESKONTROLE VAN CHEMIKALIEë IN VESELMENGSELS

OPSOMMING

In 'n industrie waar streng kompetisie geld en besorgdheid oor die omgewing van groot belang is, speel die toediening van chemiese hulpmiddels by die natkant van 'n papiermasjien 'n baie belangrike rol ten opsigte van die winsgewendheid en lewensvatbaarheid van 'n papierfabriek. In die afgelope dekade het die begrip ten opsigte van papierchemie toegeneem en sensors vir die meet van veranderlikes in die produksielyn is ontwikkel. Sommige van hierdie veranderlikes word beoordeel sowel as die instrumente wat ge-evalueer of ontwikkel is vir metings in die produksielyn in die loop van hierdie ondersoek. Prosesuitlegte om beheer oor die chemiese toedienings gedurende die voorbereiding van die pulpmengsels uit te oefen, word aangebied. 'n Oorhoofse strategie om al die proses-veranderlikes te kombineer, word terselfdertyd voorgestel. Die minimisering van prosesveranderlikheid en die verbetering van die uniformiteit gedurende produksie, is van die groot dryfvere agter die beheer wat uitgeoefen moet word oor die byvoeging van chemikalieë. Laer chemikalieë-kostes, 'n vermindering in papierverliese en gepaardgaande tevredenheid van klante is van die voordele wat verkry word. Verdere navorsing is nodig om die komplekse interaksies en veranderlikes van die chemie betrokke by die natkant van 'n papiermasjien ten volle te bemeester. Dit kan bereik word deur die verbetering van bestaande sensors of die ontwikkeling van nuwe in-lyn sensors.

OBJECTIVE

The objective of this study was to develop control loops for controlling the wet end chemistry variables in order to reduce the variability of the papermaking process. The wet end chemistry variables were reviewed and the optimum process condition discussed either from published literature information or from the results of laboratory work. Existing on-line instruments were to be evaluated and modified where necessary, and new ones or new technics were to be developed to measure some of the chemical variables. The intention was to design control loops and the required control logic. It was also intended to implement some of the control loops and to highlight the benefits of continuous on-line control of the papermaking process.

CHAPTER 1

INTRODUCTION

All industrial processes manifest inherent variability which must be minimised if the plant operation is to yield uniform, high quality product with efficient utilisation of raw materials, manpower and energy. The objective of process control is to maintain the process within well defined limits and variation. Paper machine wet end chemistry has, during the last decade, become important in both manufacturing and academic circles.The wet end is rather complicated to study and to control with its multiple interactions and constantly changing states.

The need for real time data has become more pressing. The traditional manual measurements have been found inadequate for effective control. When a process is under manual control and off-line measurements are gathered, the operator watches the trend of the data points without any relevance to real time occurences. Sometimes, he can anticipate a break through the control limits and can take action to keep the process within limits. However, depending on the relative process stability, accuracy of the data points and narrowness of the control band, the operator may only be able to take corrective action after the variable has strayed outside the process limits. This inadequacy as well as the lack of measurements of the multiple interactions leads to a poor picture of the changing environment of the papermaking wet end chemistry.

A wide range of chemicals are utilised in the papermaking furnish to impart or enhance specific sheet properties or to serve necessary purposes. A general classification of wet end chemicals is given in table 1. It is of interest to try to put the

Table 1
Classification of Wet End Chemical Additives

Additive	Application
Acids and Bases	control pH, acidity.
Alum sulphate, sodium aluminate and polyaluminium chloride	controls pH, fixes additives onto fibres, improves retention, sizing, pitch/trash control.
Sizing agents	control penetration of liquids.
Dry strength additives (i.e. starch, gums)	improve burst, tensile, add stiffness and surface strength.
Wet strength resins	add wet strength to such grades as towelling and wrapping.
Fillers (i.e. clay, talc,.TiO2, CaCO3)	improve optical and printing properties, save expensive bleached fibre.
Colouring materials (i.e. dyes, pigment)	impart desired shade.
Retention aids	improve retention of fines & fillers.
Fibre deflocculant	improve sheet formation.
Defoamers	improve drainage and sheet formation, reduce air content.
Drainage aids	improve drainage at wet end.
Optical brightners (hydros, peroxide, FWA)	improve apparent brightness.
Pitch/trash coagulants	prevent deposition and accumulation of pitch & other anionic trash.
Biocides	control slime growth and other micro-organisms.
Speciality chemicals	includes corrosion inhibitors, flame proofing and anti-tarnish chemicals, ...

chemical additives market, with respect to the paper industry, into economic perspective. Perhaps, on average, 10% of the cost of making paper can be attributed to chemicals with 70% being the cost of the raw furnish.

A typical control loop consists of three basic components, i.e. a sensor (with a transmitter), a controller and a control element. The interaction of these components is shown schematically in figure 1. The sensor is at the heart of any control loop, with automation not possible without reliable indication of dependent variable behaviour. The controller compares the signal received from the sensor to a desired value, referred generally as the "set-point". The controller acts to reduce the error and brings the actual value towards the desired value by means of a control action to a control element, a chemical stream in our case. The controller action as well as the response of the control element is dependent on the control strategy and control practice which is defined to take into account the behaviour of the dependent variable and the interaction of the other variables.

Developments during the past decade have advanced papermaking chemistry process control to the point where it has become of recognised importance to the papermaker. The understanding of the chemistry of the papermaking process and measurement technologies have improved greatly allowing the development of a control strategy for the various chemicals added to this dynamic environment.

We will review some of the important wet end chemistry related variables and discuss measuring sensor and control strategy. There is much more research required before mastering the

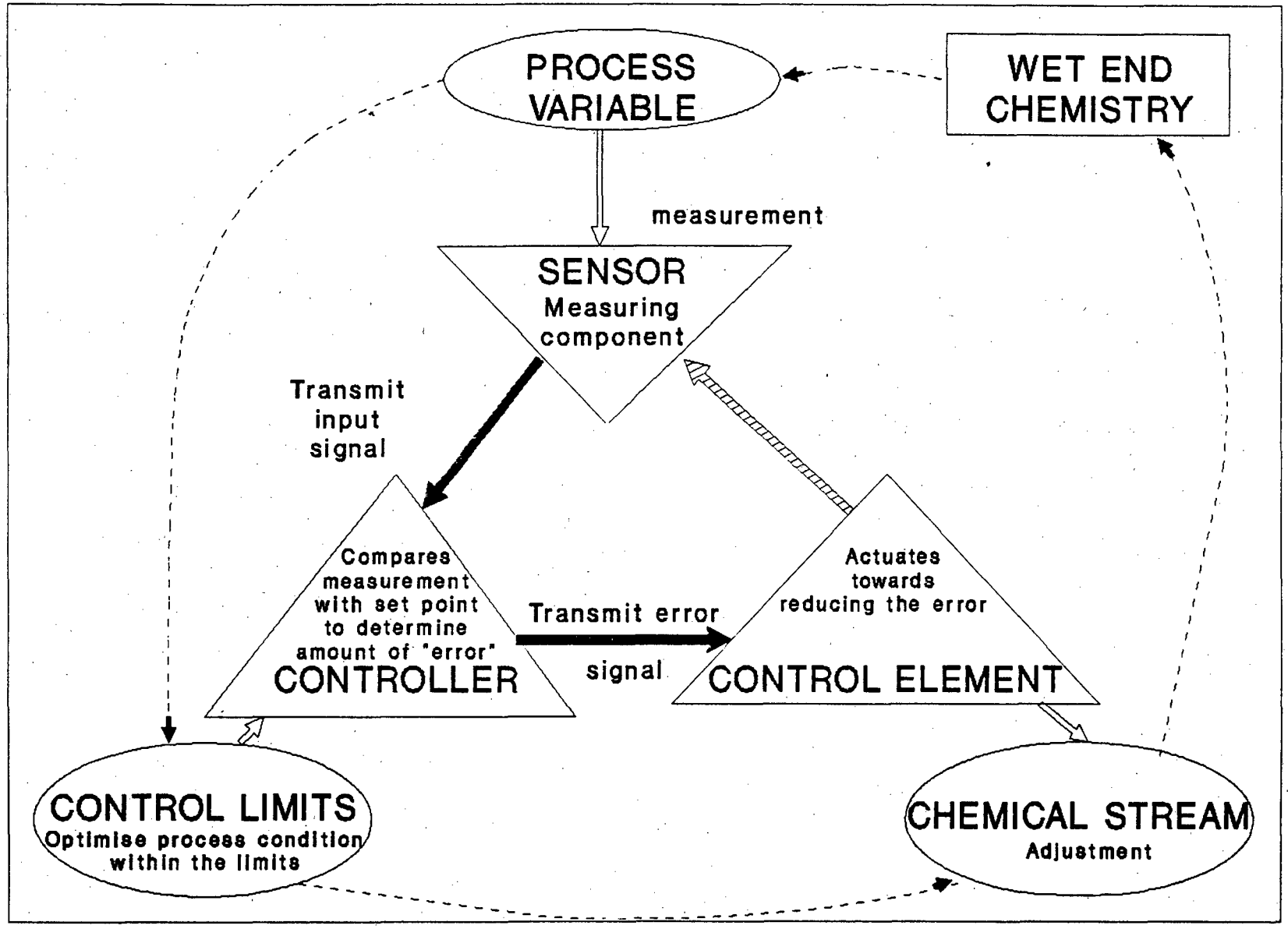


Figure 1 : SCHEMATIC OF CONTROL LOOP

wet end puzzle and optimise the process. However, it is suggested that the papermaker proceeds to implement the control strategy a piece at a time and integrate new process understandings and sensor developments as they become available.

CHAPTER 2

CONTROL PHILOSOPHY

Current control practices in stock preparation and at the paper machine can almost be characterised as "trial-and-error" approaches that are strongly driven by the observation of paper properties at the dry-end of the machines. Creasing and poor moisture profiles are signs of poor dewatering leading the papermaker to investigate drainage, chemicals addition and pulp preparation. If a dry strength goes out of control, refining intensity, dry strength additives addition or pulp ratio is changed. In this approach, the papermaker makes changes that directly address the symptoms. Through experience, he develops a collection of empirical responses for each paper property symptom. This approach leads to the production of "broke" or unsealable paper and poor productivity due to the lag time between the observation and the correct variable change.

A second reason for initiating a process control strategy is based on the performance of a paper machine which degrades to the extent that the runnability of the machine is threatened. In these instances, the correct control action is not obvious because the situation can be the end result of the interaction of several different contributing variables over a period of time. A given symptom may arise from different sets of conditions and depends on the history of the system, i.e. how it got to the state it is in. Likewise, the system response to any given control action will also depend on the system history. The papermaker needs to have more information about the chemistry of the pulp preparation before selecting a control

action. He must also have an understanding of the interactions that occur between the various components of the system and how these interactions influence the machine operation and paper quality. This information needs to be relayed on-line to ensure prompt control action to avoid poor or deteriorating machine runnability and paper quality.

A third reason is the need to minimize the variable cost of producing paper. In a very competitive and international market, the variable cost of producing an item must be kept as low as possible. Fibre furnish is the most costly component followed by the various chemicals added at the wet end in the manufacturing of paper products. There are several loss points at the wet end of the paper machine, such as cleaner rejects, screens rejects and white water chests. The amount of papermaking materials lost at these points will be directly related to their concentration in the rejected stream (Frankle et al. 1976). These losses will need to be recovered before effluent discharge, resulting in increased effluent treatment plant (capital cost) and water treatment cost, as well as sludge treatment and discharge costs. Furthermore, poor quality and unsaleable paper, due to the variability of the wet end chemistry, will need to be reprocessed by incorporating the furnish back into the wet end. This will increase the cost of producing saleable paper and in addition will upset the delicate balance of wet end chemistry.

The fourth reason is related to environmental and government regulations, where discharge of polluted streams must be reduced. The organic content and other characteristics of the effluent from the paper mill, measured as BOD, COD and AOX, must be kept within stringent limits which necessitate

expensive water treatment processes. The latter can be attained by improving the wet end control at the paper machine.

Recent worldwide technical advances in the development of sensors will have a significant impact on stock preparation and the wet end performance of a paper machine. There are a small number of on-line wet end chemistry sensors available to the papermaker and curiously enough, not all of them are being widely applied by the industry. The paper industry has preferred taking advantage of the available prooven on-line instrumentation, but has been hesitant to accept newer ones as for example thin stock consistency meters, zeta potential sensors. This is a strange situation in view of the tremendous amount of time and energy spent collecting wet end chemistry data for routine control and experimental purposes by manual, off-line methods. A survey of the wet end measurements taken at 35 mills was carried out and reported by Scott (1984). A total of 93 different quantities were listed but only 5 were measured on-line with 3, i.e. pH, flow rates and thick stock consistency, being the most common.

The well recognised complexity of the wet end chemistry phenomena has resulted in the "hand-off" attitude that is prevalent in so many mills today. However, many studies aimed at elucidating wet end chemistry mechanism and fundamentals have been carried out in laboratories and mills by papermakers, suppliers, consultants and academics (Gunder et al. 1975). These studies have gone far towards explaining most of the fundamentals as well as the interactions among various factors. Currently there is sufficient understanding to develop and implement various wet end

chemistry control strategies. However, this has not been applied and has limited itself mainly to retention control systems at the paper machine (Scott 1983, Lindstrom et al. 1984).

For the development of a control strategy, a paper machine producing fine or part-mechanical grades from softwood and mechanical pulp in acidic medium was choosen as an example. Although the implementation of a control strategy will be similar for paper and board machines producing different grades with different furnishes, each control system will need to be defined individually for a production line, taking into consideration the particular wet end chemistry. The dominant factors affecting the papermaking wet end process are compiled in the Ishikawa diagram shown in Figure 2. By identifying the most probable sources of potential problems, control can be applied at the most effective points.

Some of the variables affecting the wet end chemistry process will be reviewed and the relevant sensor will be evaluated. As time progresses, other sensors (Tornberg et al. 1993) will be available which are more elaborate or more acurate and it will be possible to measure and control more variables. The basis of the control strategy for each variable will be dicussed where appropriate, but many chemical feed controls will need an overall analysis of the system before a control action will be instituted.

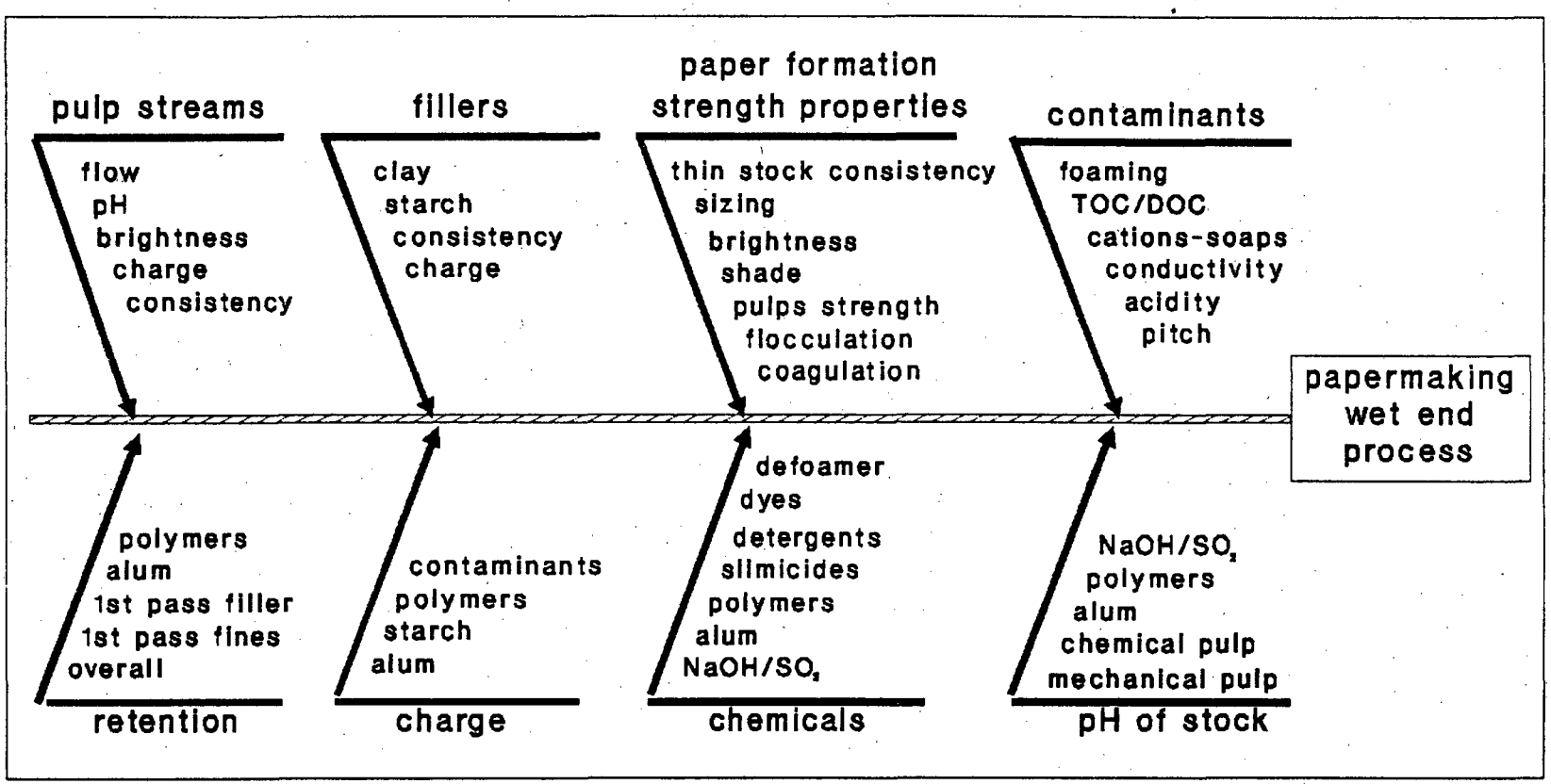


Figure 2 : PAPERMAKING WET END PROCESS
DOMINANT FACTORS AFFECTING THE OPERATION

CHAPTER 3

PROCESS VARIABLES AND CONTROL

3.1 pH CONTROL AT THE WET END

Of all the chemical variables that affect quality and production performance in a paper mill, pH is probably the most vital. It also tends to be the most overlooked. There are two main reasons. First, pH is considered to be a variable that has importance at only the most basic point in the process. Rarely is it looked at as a variable that has a distinct effect on all points in the process, with each stage interrelated to the others. Secondly, it has traditionally been a difficult parameter to measure and to control in the papermaking process. Combined with this difficulty is the lack of knowledge of pH chemistry.

3.1.1 Furnish pH Control

Furnish pH measurement is required no matter which source of pulp is utilised. Be it purchased, recycled or directly used from the pulp mill on the same site, pH will change. Many mills assume that controlling white water pH is all that is required for furnish pH control. While this scheme may seem adequate, it does not recognise the detrimental side effects that can result, especially in mills that have closed or semi-closed recycled loops. pH influences the solubility of the dissolved chemical substances in the system. Adding white water to stock and missing the predetermined pH targets can result in the complexing of unwanted ionic species that must be dealt with and carry through to the final product or continue to reappear in the white water.

3.1.2 Chemical Pulp Preparation

The pH of chemical pulp during slushing should be maintained in the alkaline zone (7-7,5) for improved fiber strength development. Swelling time of the chemical pulp fibres in a hydrapulper is influenced by the chemical environment in which the fibres soak. Alkaline medium promotes fibre softening, swelling and fibrillation, and the handsheets have excellent physical properties (Jayme 1964), (Chen 1984), whereas acidic sulphonation gives poor beating response and paper properties (Law et al. 1983).

A low pH hardens the fibers and makes them less flexible, favouring fibre cutting and fines generation in the refiners (Hietanen et al. 1990) whereas an alkaline medium softens the fibres and makes them more pliable resulting in faster strength development and leading to longer more fibrillated fibres (Beach 1984). However, refining at too high a pH can cause yellowing and brightness reversion of the bleached fibres.

Futhermore, it will take more energy to refine a furnish to the same freeness as pH drops (Mercier et al 1976), (Beach 1984).

It was proposed by Katz et al. (1981) that the treatment of mechanical pulps with caustic soda results in increased strength development and arises from an increase in the number of acidic groups within the pulp. It can be assumed that the same applies to the chemical pulp during swelling and refining. Valency and electrolyte concentration measured indirectly as acidity, affects the swelling of hydrophylic gels (Lindstrom et al. 1978-1987) and will interfere with refining, i.e. during the breakdown of the interfibre H-bond and the

solubilization of the cell walls, resulting in weaker bond formation and lesser bonded area.

In order to verify the influence of alkaline and acidic medium during chemical pulp soaking and refining, a laboratory investigation was carried out. Stock at 1,6% consistency was prepared using L/F chemical pulp and white water from a paper machine which pH was adjusted with either alum or caustic. After soaking for 20 minutes (similar to process condition), the pulp was beaten in a Valley Beater. As stock pH increased, more time, i.e. more energy, was required to attain the same pulp freeness (figure 3) whilst very little differences in strength properties (figures 4 to 6) were obtained for the same refined freeness. This is contrary to the results published in the literature and could be due to various factors, i.e.:
a) the use of the Valley Beater to simulate refining with no similarity between the refining geometry and fibrillating action;
b) different acidity of the water after pH adjustment which may have influenced soaking and swelling of the fibres;
c) lower consistency during soaking and refining compared to process condition.

This experiment should be repeated with the same refiner as in stock preparation and under prevailing process condition to give any meaningful results.

Chemical pulp pH adjustment is carried out at the Merebank mill in batches. White water from the machine is used to soak the pulp and a predetermined amount of caustic is added to the hydrapulper to increase stock pH. If the pH of the stock is continuously high after a few batches, the amount of caustic added is decreased for the subsequent batches and vice

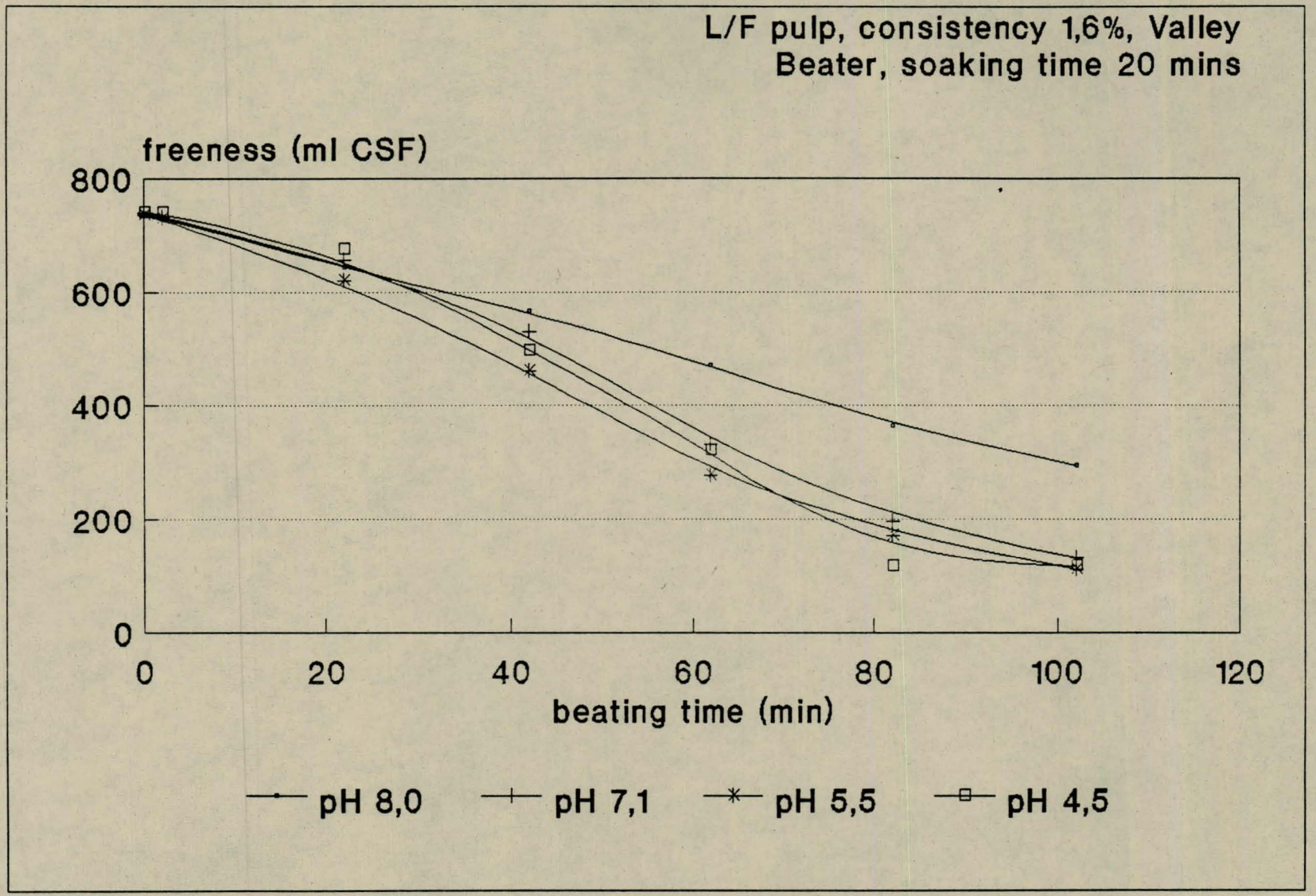


Figure 3 : CHANGE IN PULP FREENESS WITH REFINING at DIFFERENT pH's

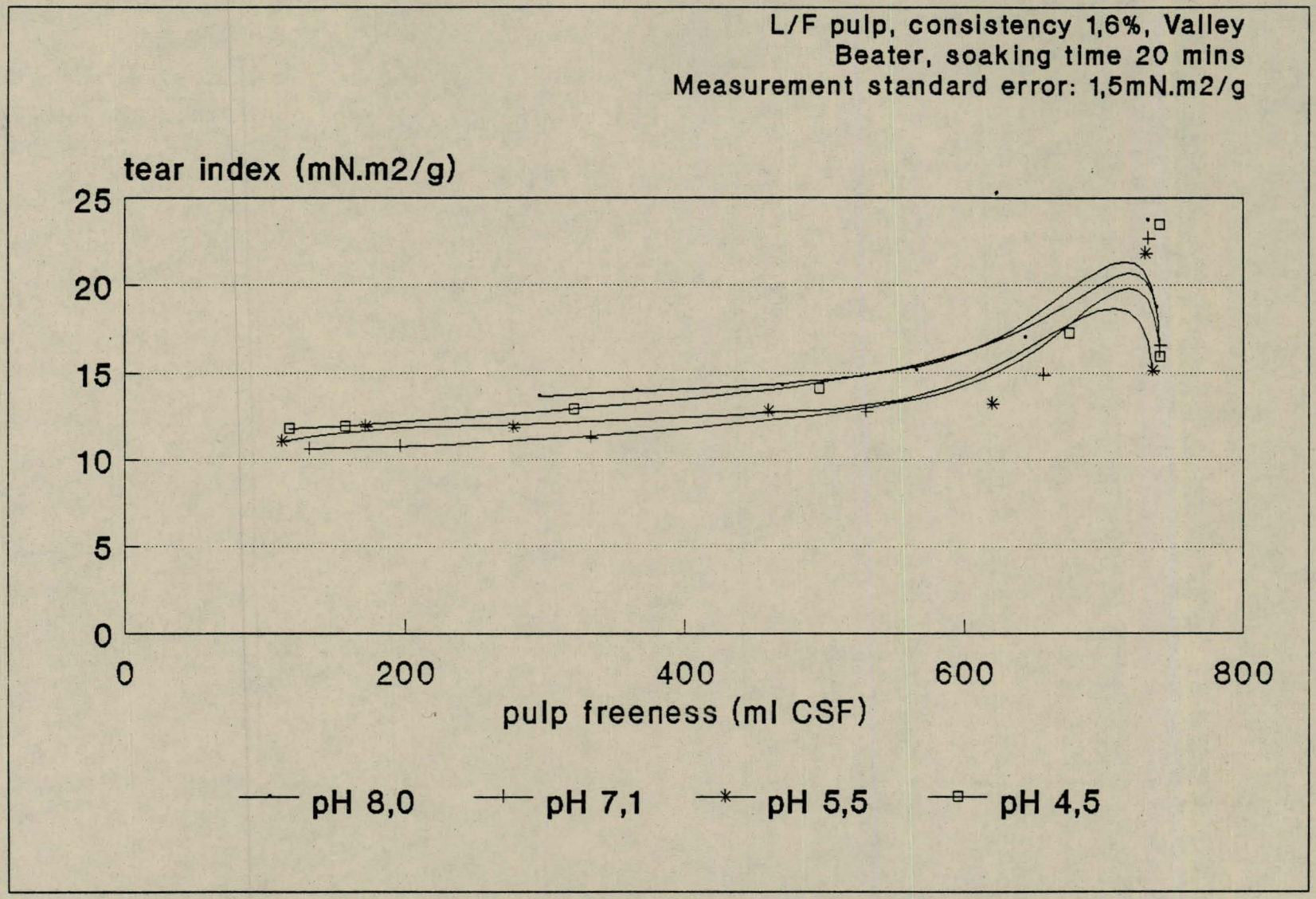


Figure 4 : CHANGE IN PULP TEAR INDEX WITH REFINING at DIFFERENT pH's

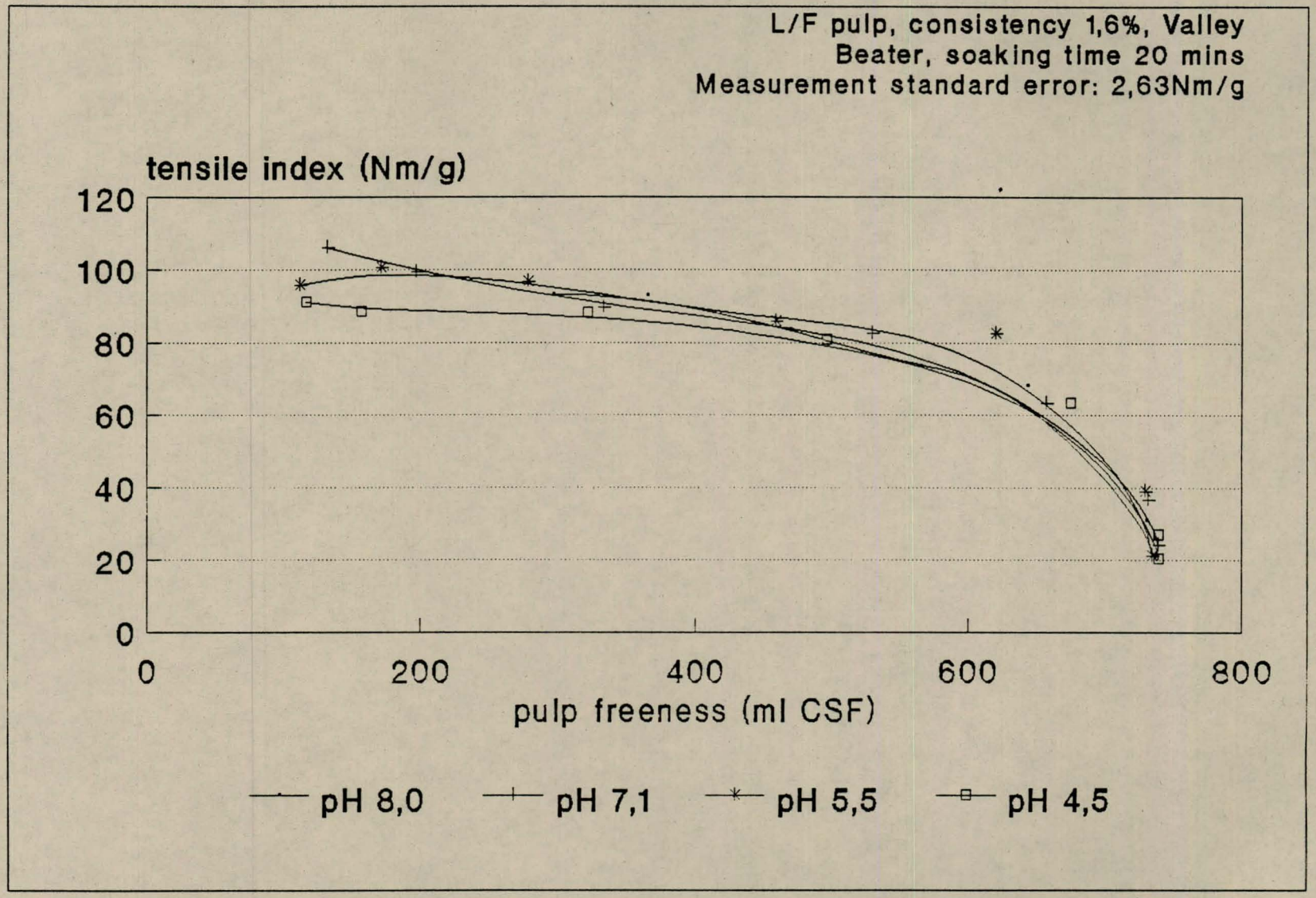


Figure 5 : CHANGE IN PULP TENSILE INDEX WITH REFINING at DIFFERENT pH's

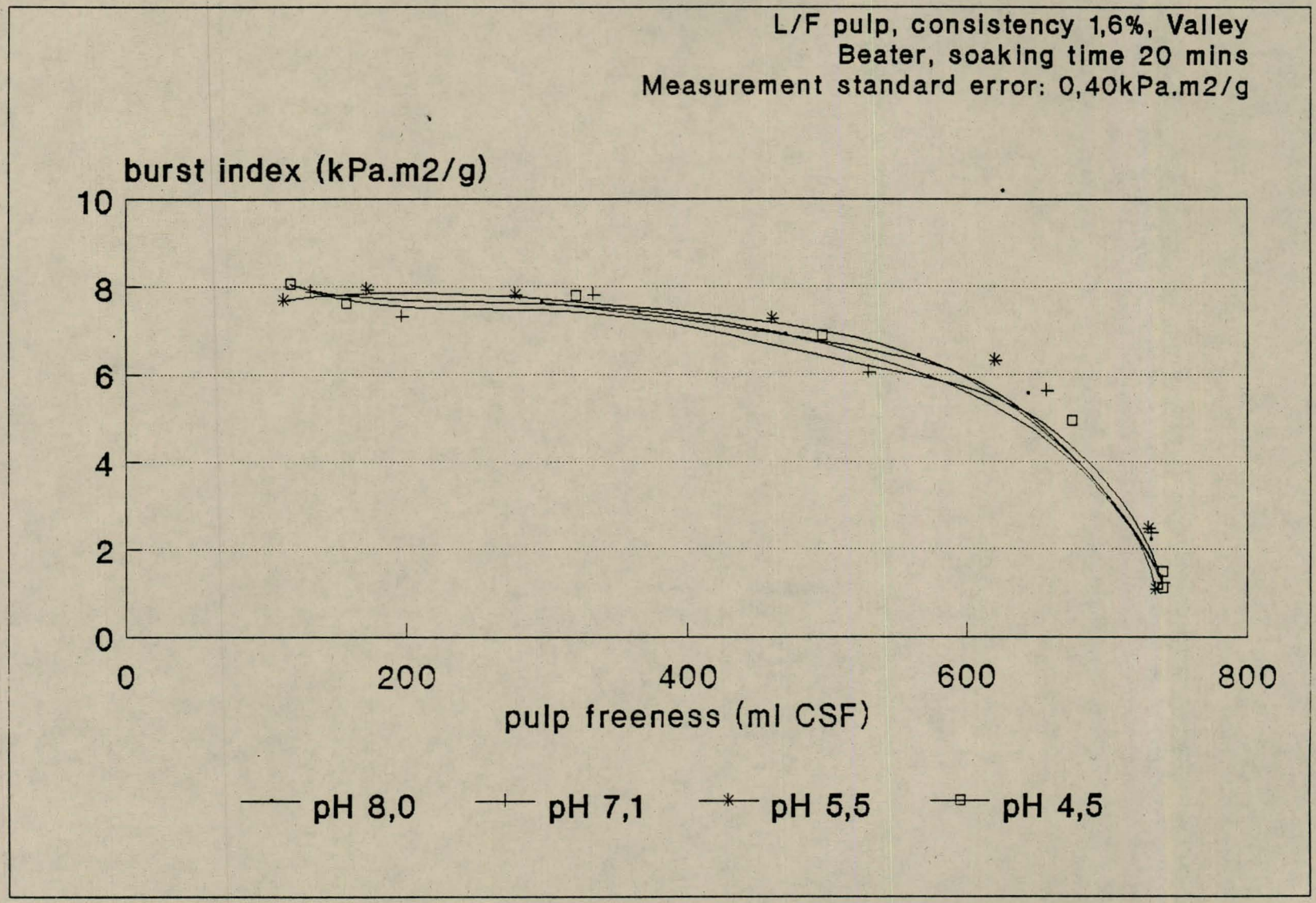


Figure 6 : CHANGE IN PULP BURST INDEX WITH REFINING at DIFFERENT pH's

versa. This procedure results in poor control of the chemical pulp stock pH (figure 7) and a proper control loop is required.

3.1.3 Mechanical Pulp Preparation

Very little information is available in the literature concerning pH control of mechanical pulp in stone groundwood and thermomechanical mills. Most of the adopted operating procedure has been derived from the equipment manufacturer recommendations and from in-house developments. One of the factors which influences pH control during mechanical processing of the wood is pitch deposition. Use of alum for pitch control is a common procedure in many groundwood and other mechanical pulp mills. It is generally accepted that alum works only in a narrow pH range, between 4,6 and 5,0. The optimal value depends on the specific mill chemistry. For mills using alum for pitch control, it is therefore necessary to control the pulp dilution water, generally white water from the paper machine in a closed water loop, tightly within the optimum pH range.

At the Mondi Paper Company Merebank Mill, the thermomechanical pulp plant was transformed to a semi-chemi-thermomechanical plant with the chips being sprayed with sodium hydrosulphite or sodium sulphite before entering the steaming vessel (Durgueil 1988). However, the use of paper machine alum containing white water for refiner plug water caused blinding of the refiner plate grooves with an aluminium and magnesium based scale. This resulted in a change-over to fresh water for the refiner dilution. No scaling nor pitch deposition occured in the subsequent refining. A modification of the paper machine wet end chemistry from an alum to an

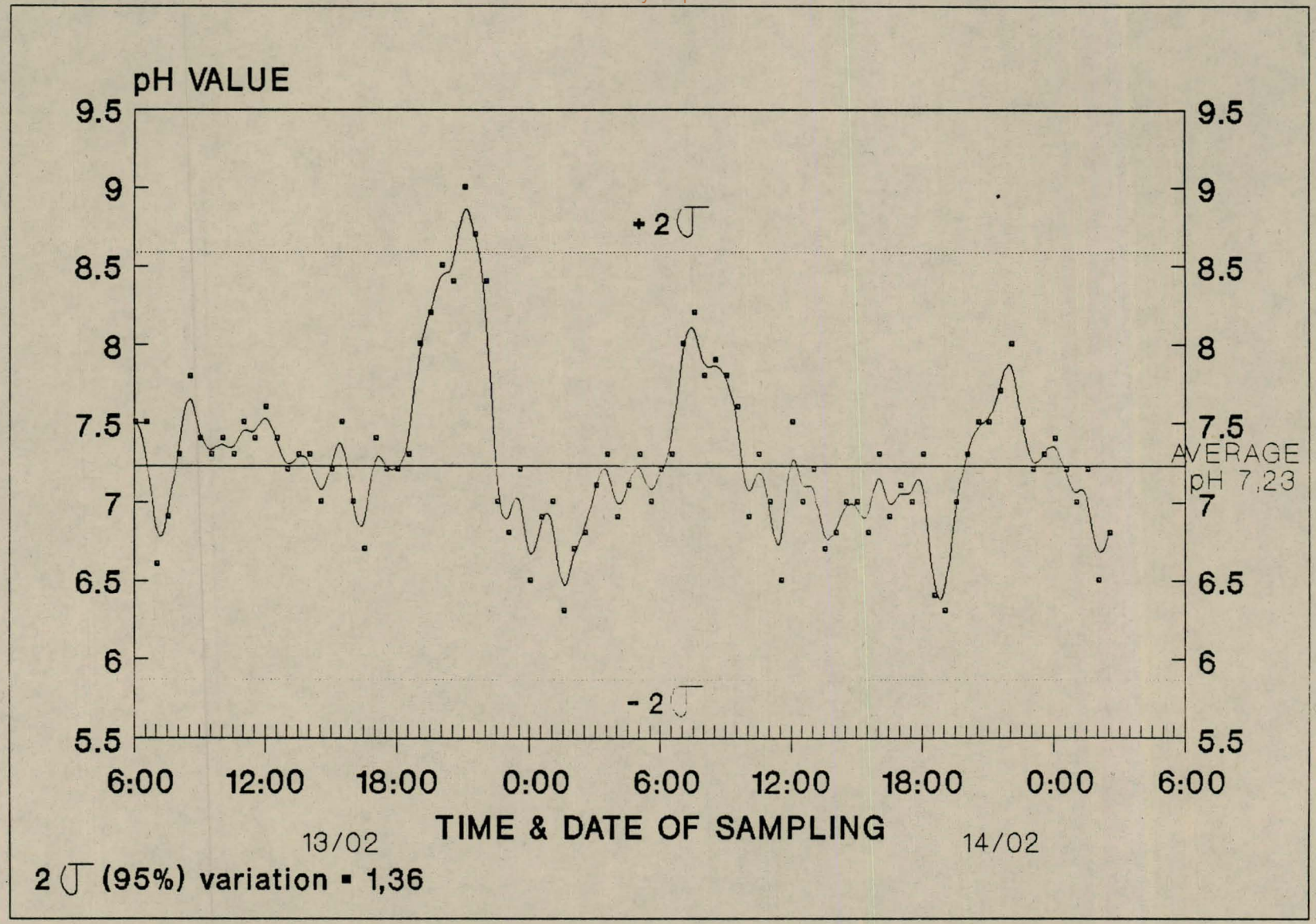


Figure 7 : pH VARIATION OF CHEMICAL PULP IN HYDRAPULPER

organic polymer retention aid based system made it possible to reintroduce the original paper machine white water for stock dilution in the refiner. pH control of the feed water will be required to ensure alkaline conditions during refining and thus proper sulphonation of the fibres.

The groundwood plant chemistry was also based on alum addition for pitch control. Excess alum was dosed in the grinder water shower systems and the pH was corrected to ±5,5 in a feedback control loop by caustic addition (figure 8). It was decided to replace alum by a polymer (Durgueil 1992), avoiding the use of alum and caustic in the system and allowing the system to adjust itself to the natural wood pH of ±6. A higher system pH resulted in reduced corrosion, lower chemical usage, lower acidity and contaminants, and higher pulp brightness. pH control was discontinued and the use of alum was stopped. Apart from minor fluctuations, the pH of the system stabilized within the natural wood pH range.

Apart from pulping, the bleaching processes are the most important areas for pulp pH measurement and control. The subject of pH control would require a book in itself. A thorough study of the chemistry of each bleaching process is required before specifying targets. Optimum pH values are required for all bleaching reactions, i.e. peroxide bleaching at pH 10,5-11; sodium hydrosulphite bleaching at 5,5-6,0; sodium hydrosulphite from Borol process at 5,2-5,8, etc.

3.1.4 Paper Machine Wet End

Blend and machine chests are areas where different furnishes are mixed, chemical additives are introduced and extremely

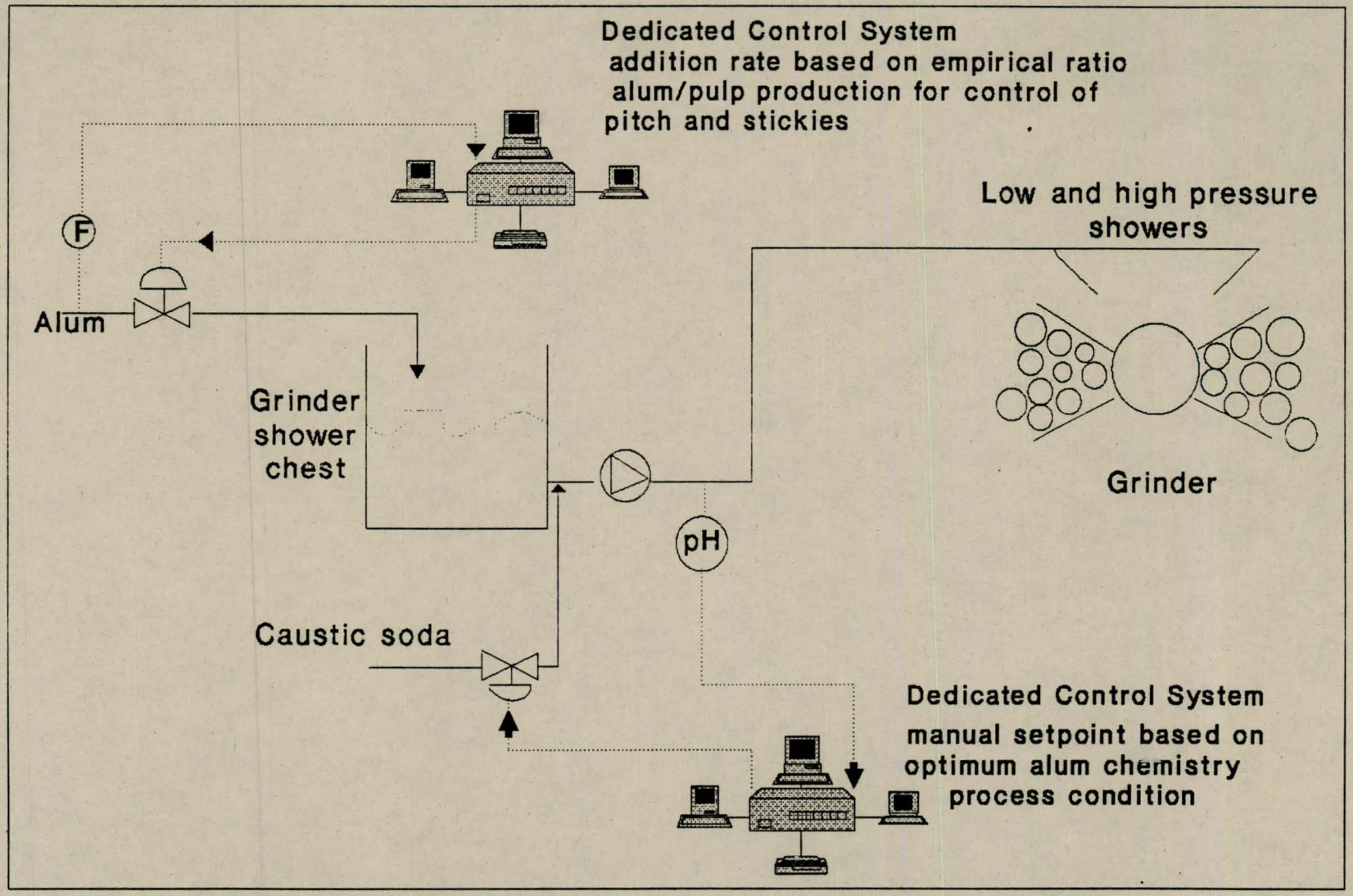


Figure 8 : GROUNDWOOD PULP PREPARATION
PRESENT pH CONTROL LOOP

complex chemical interactions can result. The blending of raw materials and chemical additives is largely influenced by pH chemistry and determines the performance of a number of parameters such as drainage, formation, retention, adsorption, dispersion, viscosity, slime accumulation, alumina carryover,etc. Considering the above, it becomes essential to exercise a tight control over pH. pH should be controlled at each point in the process where chemicals or stock are added. The more complex the furnish, the more important it becomes that thorough chemical analysis be performed to determine optimal pH targets for each chemical addition point. Systems using alum in the furnish, with or without rosin size, must consider white water pH, furnish pH and stock pH as a part of a complete control strategy (Springer et al. 1982).

Headbox pH control is common. This is the last place to get it right! Traditionally, pH has been measured in the wire pit or in an overflow box (Johnson 1982, Gray 1982). Locating the sensors in this area leads to clogging or fouling, resulting in unrepresentative sampling or too much lag time in the control loop. Because of the averaging effects at the wire pit, instantaneous variations of headbox pH that affect overall performance are not noticed. Measurement of wire pit pH is, in effect, the measurement of white water pH. It is related to, but it is not, headbox pH.

Control of the formation of metal soap and control of corrosion are two other reasons for independently controlling pH in the stock preparation area. Firstly, the formation of metal soap, which contributes to pitch deposits is controlled by the availability of dissolved soap anions, which in turn is controlled by pH (Allen 1988). pH often affects the colloidal stability of the

dispersed resin (Allen 1975) as well as other forms of depositable material (Stradzins 1972). The deposition of metal-soap originates from multivalent metal ions in the wood or hard water, reacting with the soap of a fatty or resin acid. Under acidic pH values, the concentration of soap anions is low because they combine with hydrogen ions to form insoluble fatty and resin acids. The total organic content of the water will probably increase with an increase in pH as the hemicellulose materials dissolve from the fibre wall.

Secondly, proper pH control minimizes equipment corrosion which can be approximately 30 percent of the maintenance cost of a paper production line (Thorpe 1982). This adverse economic impact may be reduced by avoiding low pH conditions and properly controlling the bleaching operation to avoid the formation of thiosulphate during sodium hydrosulphite bleaching (Russell 1985).

3.1.5 pH Control Strategy

Accurate and reliable pH measurement is the heart of pH control and sensors are the heart of measurement. Sensors that can measure directly pH in line is a must to avoid fouling or scaling of the probes in the pulp stock or lean water. In the past 10 years, development of this type of sensor has occured and various types are available on the market. Measurement and control problems as well as tips for the sensor installation are summarised by Spriggs (1989 - 1992).

Chemical pulp pH control can be carried out simply with a feedback control loop (figure 9). An on-line pH probe inserted before the dilution water holding tank (figure 10) measures

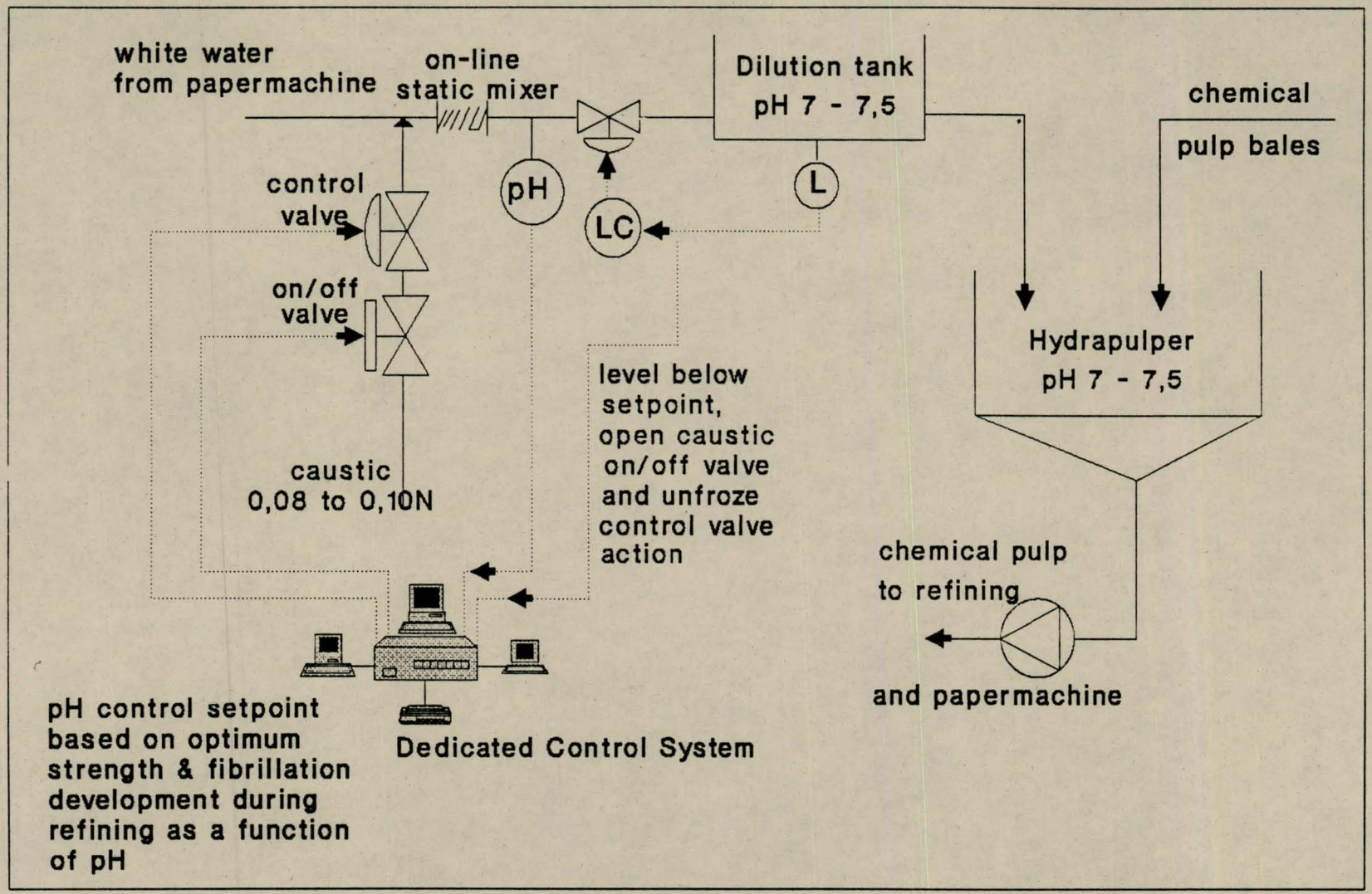


Figure 9 : PROCESS CONTROL OF pH
AT THE CHEMICAL PULP HYDRAPULPER

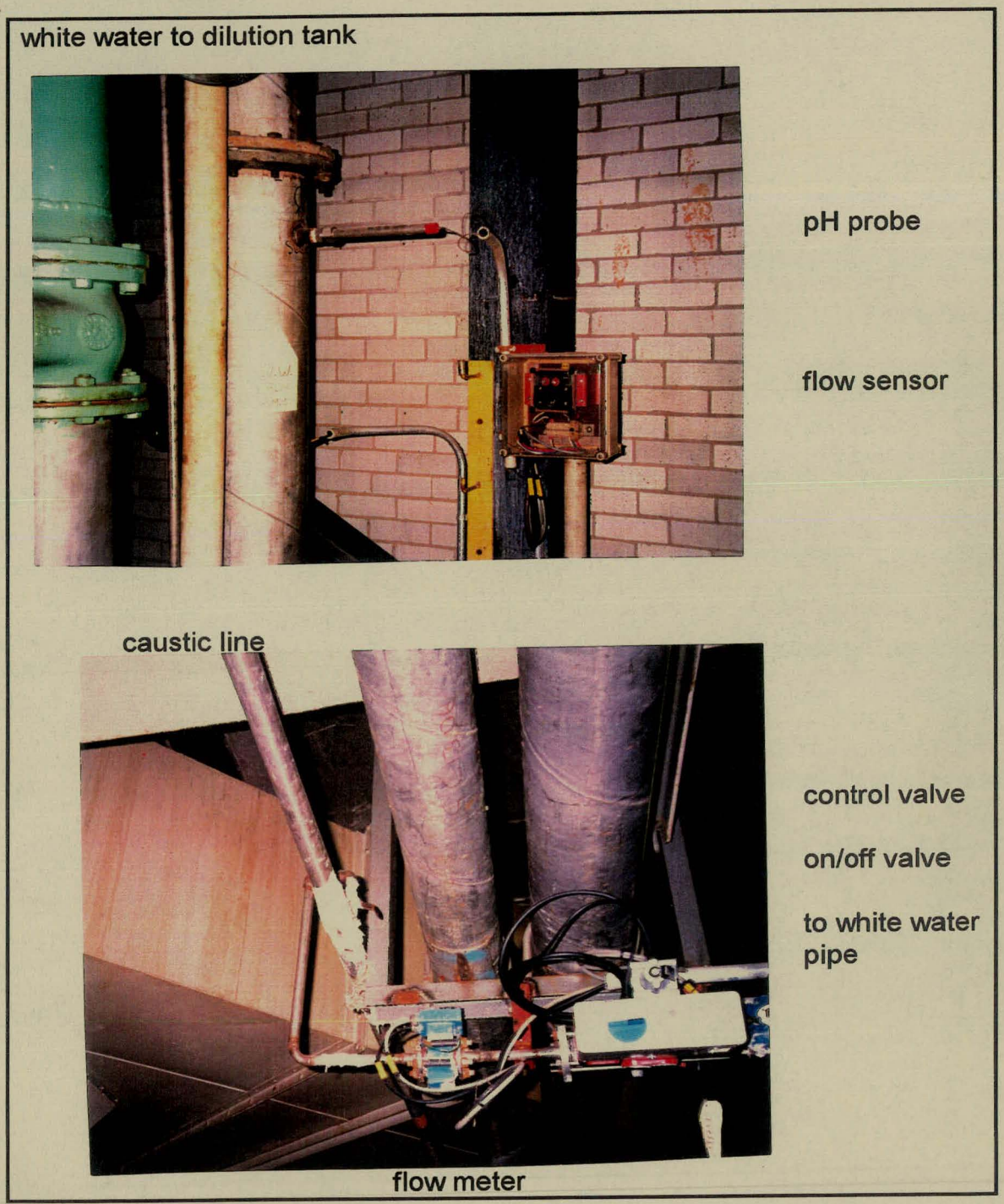


Figure 10: INSTRUMENT INSTALLATION FOR pH CONTROL AT THE CHEMICAL PULP HYDRAPULPER

continuously the pH of the paper machine white water and sends a signal back to a controller. The controller adjusts the flowrate of caustic added before the pH sensor via a control valve. It is imperative that proper mixing is attained before the pH sensor and it is recommended that an on-line mixer be inserted into the pipe and the caustic strength be diluted to avoid hunting of the control at very low flowrates.

Furthermore, as this is a batch process, it is necessary that the caustic flow be interrupted when the level in the dilution tank is high, i.e. no flow in the pipe. This can be attained by installing a flow switch in the white water pipe if the line is constantly pressurised, or taking the signal from the level sensor in the dilution tank and feeding back to the control valve forcing it to close or better, by installing an on-off valve in the caustic line before the control valve and suspending the pH control action.

For mechanical pulp preparation, a similar control will apply. For example, in the groundwood plant, it is necessary to operate within the required pH range for the polymer. In this case, a feedback control loop on the shower water chest is installed with an on-line sensor in the pipe to the grinders, controlling the addition rate of caustic or sulphuric acid added to the chest. With the polymer being the only chemical added during the pulping and pulp cleaning processes and operating satisfactorily over the pH range 5 to 6, it is also possible to control the sodium hydrosulphite bleaching pH using the same loop. A second on-line pH sensor is inserted after the decker chest which will feedback the set point value for the primary loop (figure 11). If peroxide bleaching is used, the latter sensor is not necessary but pH control is required in the bleaching plant (discussed later under brightness control).

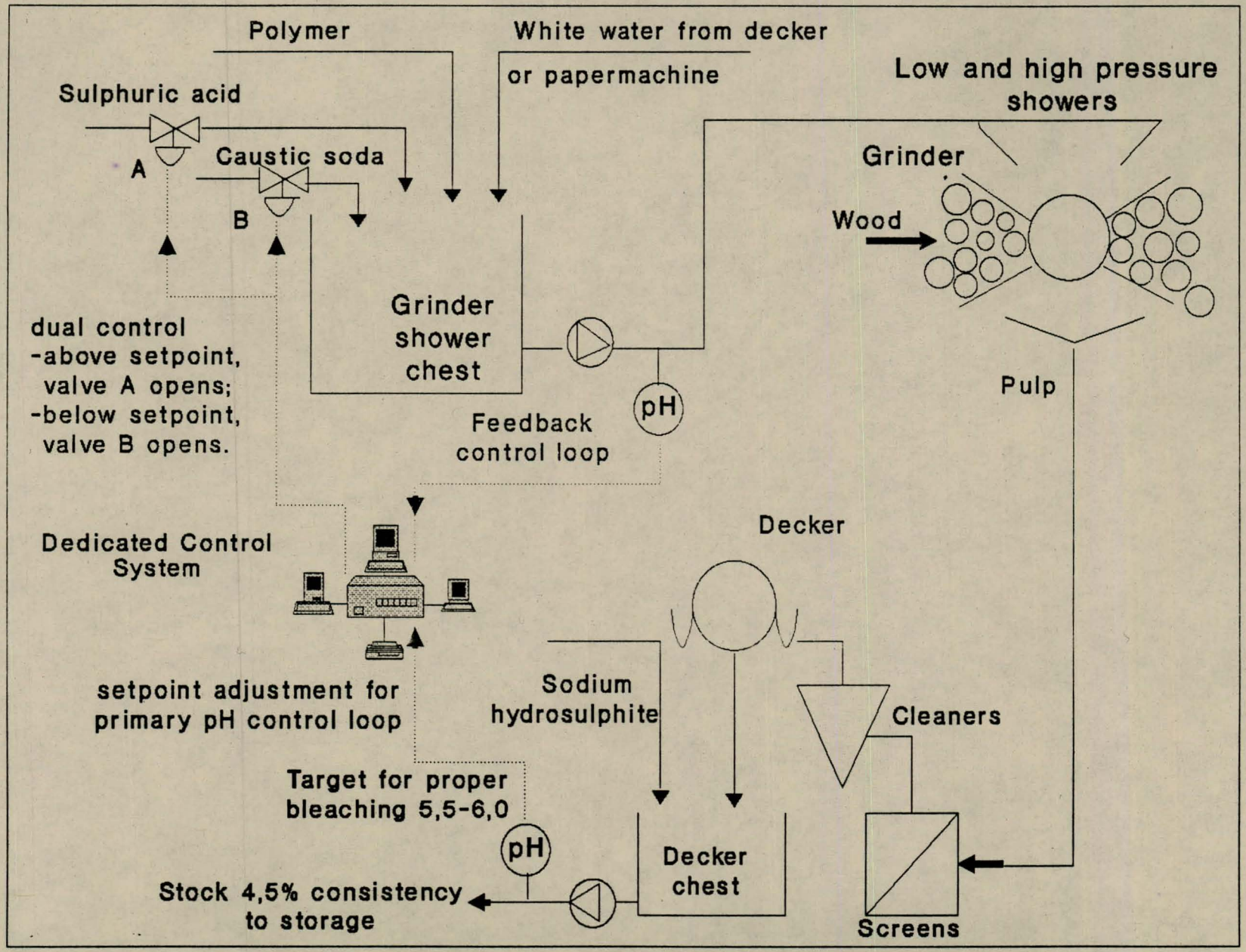


Figure 11 : GROUNDWOOD MILL pH CONTROL

In the thermomechanical plant, the control will be simpler with only pH control required before sodium hydrosulphite addition. When potable water is used in the refiners and with sulphonation of the chips, the pH of the pulp may tend to be on the neutral side (± 6,5 - 7,0) and a slight addition of sulphuric acid may be required for proper bleaching. A feedback control loop measuring the stock pH after the deckers and addition of sulphuric acid into the decker chest may be contemplated (figure 12).

In the stock preparation area and the headbox approach flow, each chemical addition may require a certain pH for proper reaction and a control loop should be installed each time. However, this may become onerous and furthermore, most of the chemicals used at the wet end must perform within the same pH control range to avoid complexing and unwanted precipitate formation. It is possible to have only one control loop in the approach flow piping with pH measured on-line in the headbox recirculation pipe (figures 13 & 14) and sulphuric acid/caustic soda addition controlled in the blend chest.

Headbox pH control will be discussed later under the section dealing with the alum-rosin sizing control strategy.

At start up after a paper machine planned maintenance, addition of sulphuric acid should be envisaged for the control of pH, whenever fresh water is used in the make-up chests. This will avoid unwanted chemical reactions when using the water for pulp stock dilution. Another area which must be mentioned is shower water pH control. This water is being used for felt washing and headbox internal spraying. While not related to the control of chemicals, addition of water with a

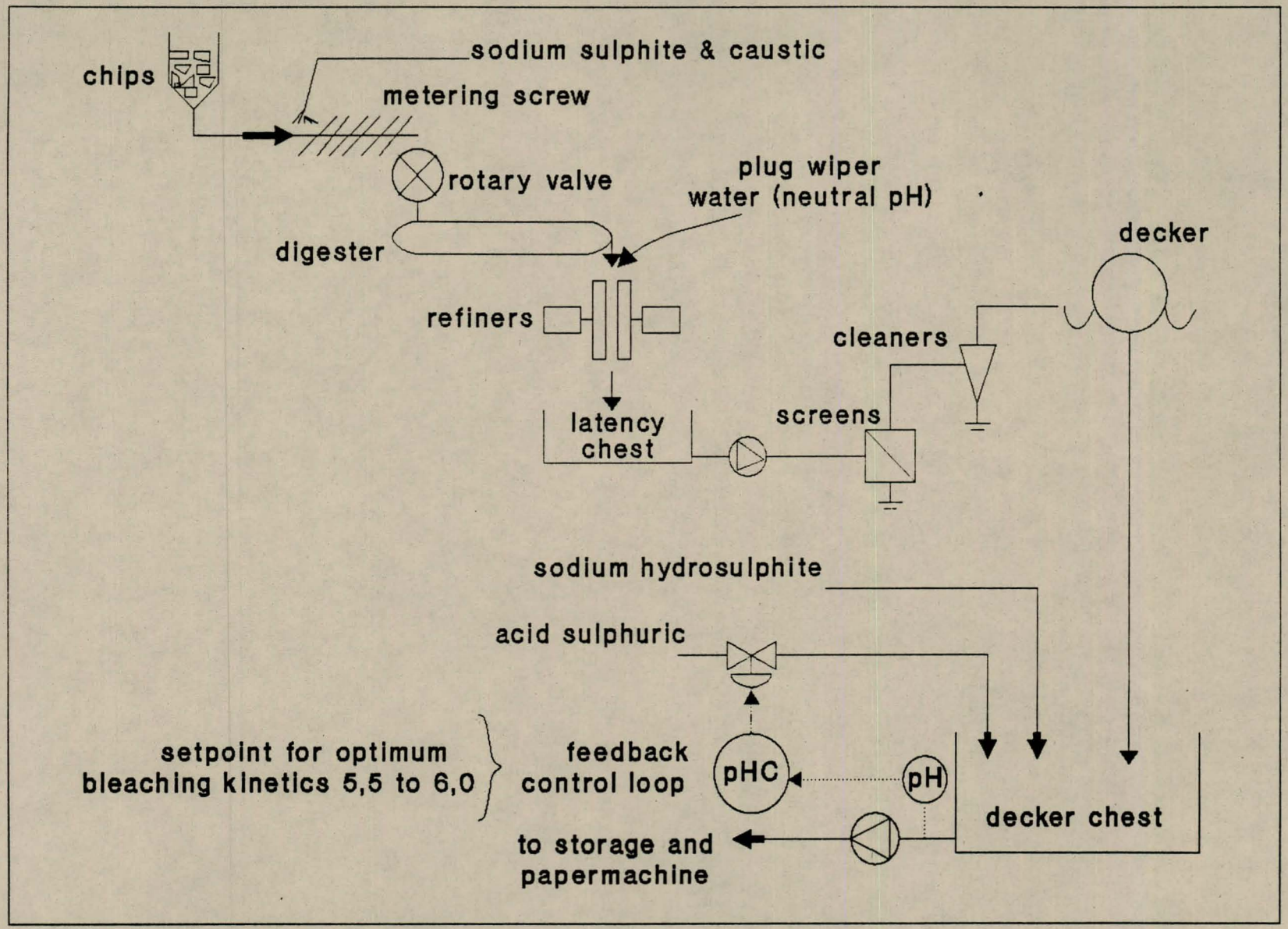


Figure 12 : TMP PULP pH CONTROL

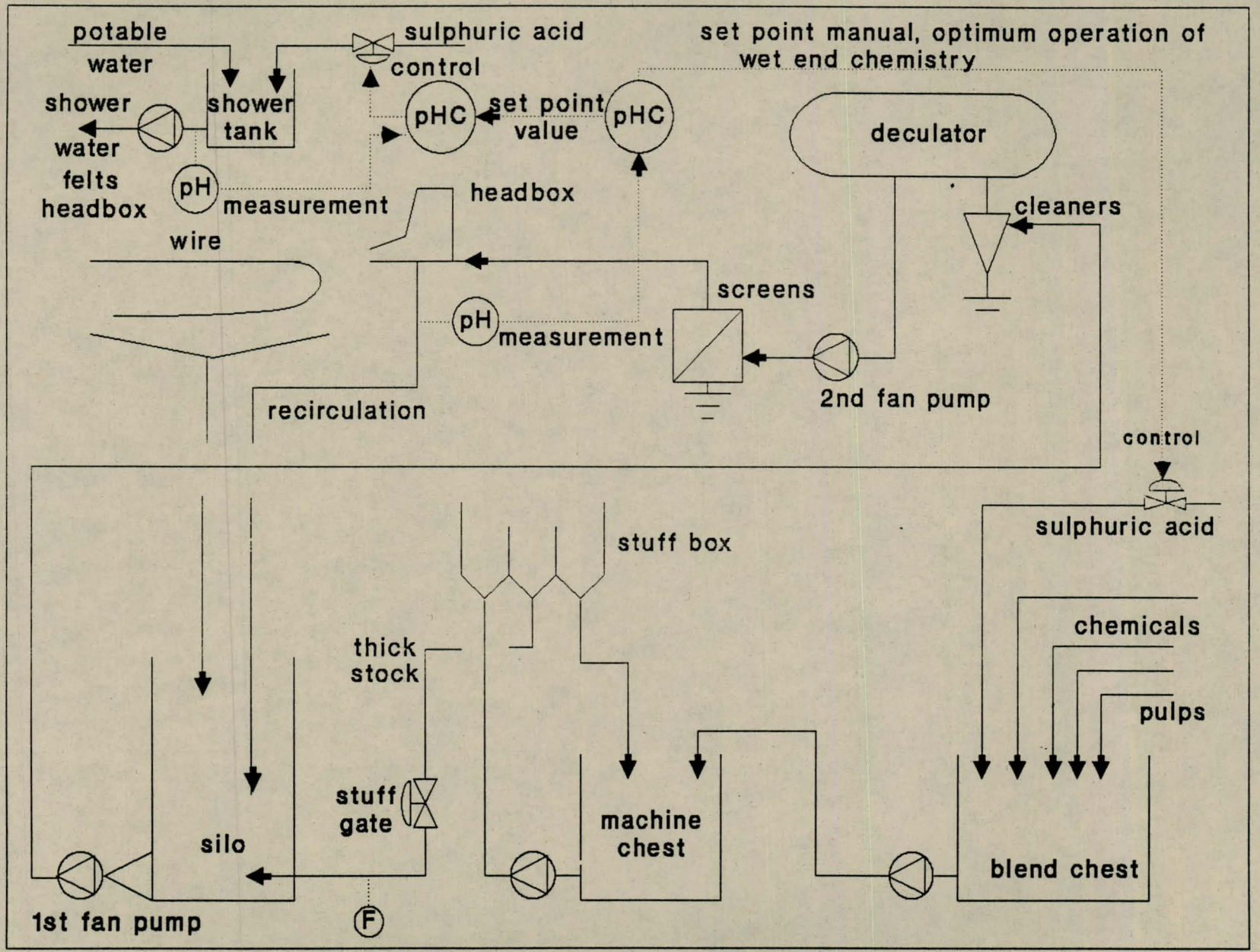


Figure 13 : APPROACH FLOW pH CONTROL

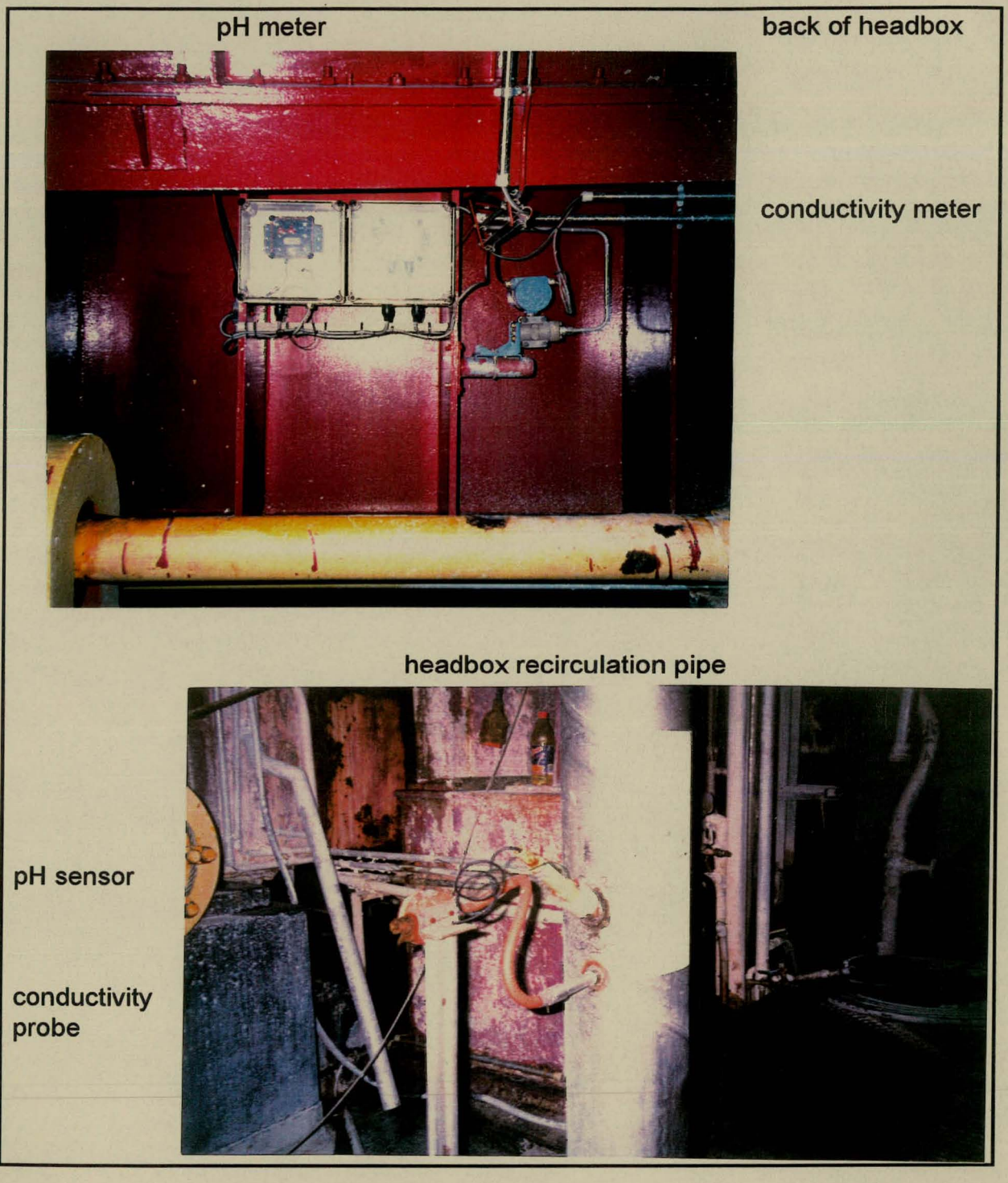


Figure 14: pH & CONDUCTIVITY MEASUREMENTS IN THE HEADBOX RECIRCULATION PIPE

different pH to the wet end system will result in pH shock, alum precipitation or deposit formation. The shower water must thus be acidified to the same pH as the wet end water. A simple control loop for the chest must be installed with the headbox pH sensor value being taken as setpoint for the control loop of the shower water pH.

3.2 ACIDITY CONTROL

3.2.1 Importance of Acidity

At a given temperature, the intensity of the acidic or basic character of a solution is indicated by the hydrogen ion activity or pH, i.e. the negative logarithm of the hydrogen ion concentration in the solution.

The addition of a given amount of alkali in order to increase the pH of acidic solutions of same pH will result in a varying end-point pH due to the different concentrations of a weak acid and its salt (conjugate base) present in the solutions. The more concentrated the solution, the greater will be the resistance to pH change upon the addition of a base. The quantitative capacity to react with a strong base to a predetermined pH is referred to as the acidity of the solution.

The greater the acidity measurement, the greater is the concentration of ions in the solution and hence the amount of alkali required to vary the pH of the solution to a predetermined pH. The variable presence of ions in the solution will therefore affect the ability of the aqueous solution to carry an electric current, i.e. the conductivity (figure 15). Therefore, it can be said that there is a relationship between the conductivity of the solution and the amount of alkali required to modify the pH to a predetermined level.

In an acidic papermaking process where alum is used, the acidity of the white water will be dependent on the aluminium ion and composite concentrations, the residual amount of flocculant ions and the dissolved trash. Due to the varying

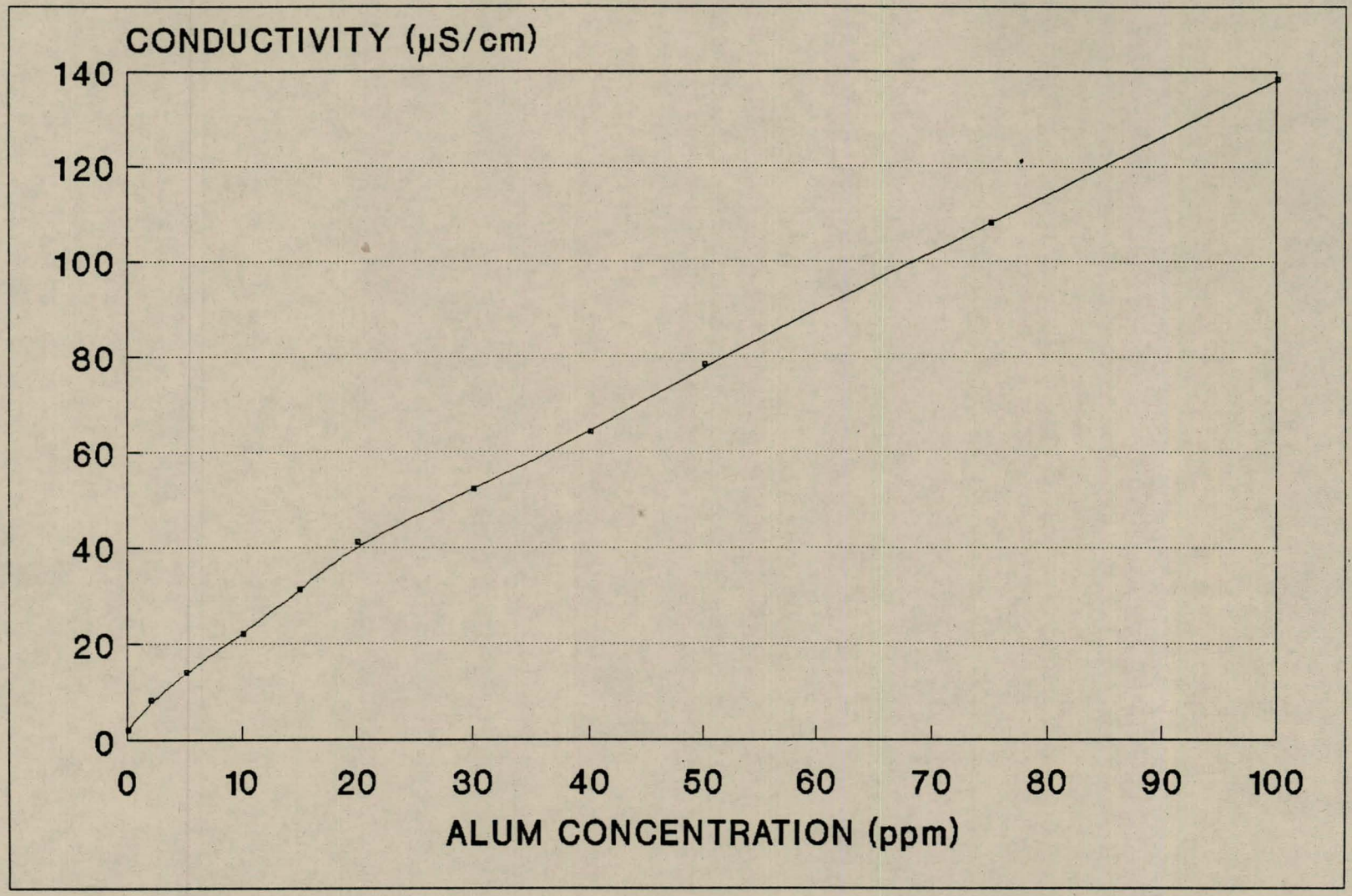


Figure 15 : CONDUCTIVITY VERSUS ALUM CONCENTRATION IN SOLUTION

influence of any of above concentrations, a straight relationship between conductivity and acidity at a given pH was not expected. However, a good enough correlation for practical process control was found (figure 16). This will allow the determination of the amount of caustic (alkali) required to bring the solution to the pH needed for proper papermaking operation from the single on-line measurement of pH and conductivity. The closure of a papermachine water system leads to a build-up of dissolved solids in the process water, including both organic solids and electrolytes. Of the latter, the most frequently added is alum. Its accumulation in a closed paper machine system makes itself felt in a number of ways. Among them are a high dissolved sulphate ion concentration, deposition of alum scale and an increase of free acidity. As a result of the latter, the process water pH is lowered. Once this falls below about pH 4,4, a buffered situation is set up, where the pH is insensitive to changes in the amount of alum added (figure 17) and can result in large amounts of alum wasted into the system. Under these circumstances, total acidity becomes a much more reliable parameter than pH for controlling the addition of alum to the machine.

One of the main problems in paper sizing has been the correct proportioning of rosin and alum. Despite the extensive research done on this subject, the papermaker's approach is still empirical. It is generally accepted that alum should be present in excess (Casey 1960) with pH somewhere on the acid side. The optimum pH for effective sizing is not constant and varies from one machine to another, depending on variables such as fibre furnish, sizing agent, fresh water supply and backwater system closure. It has been suggested (Batier 1967, Watkins 1962) that acidity of process water is a

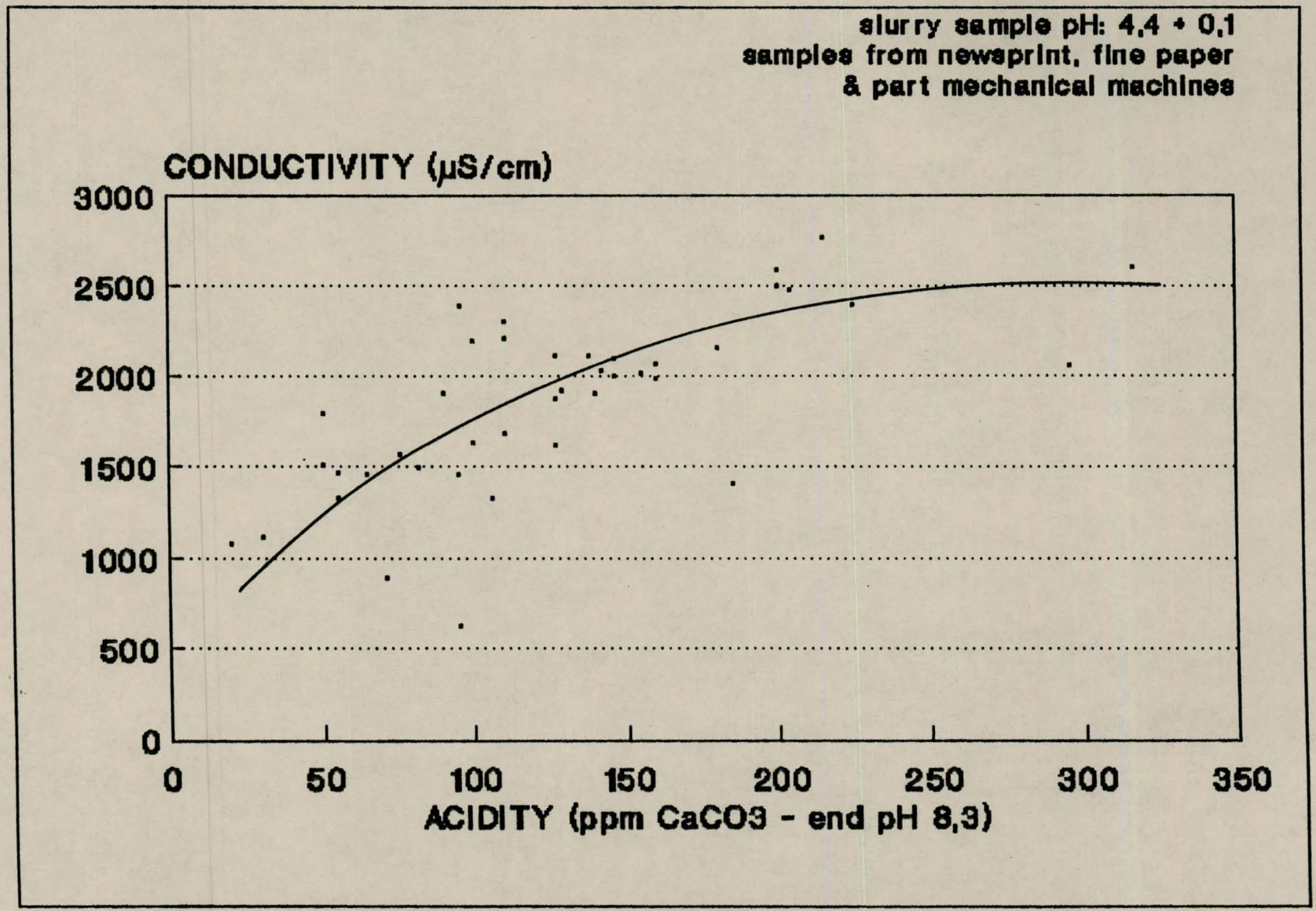


Figure 16: ACIDITY AND CONDUCTIVITY RELATIONSHIP

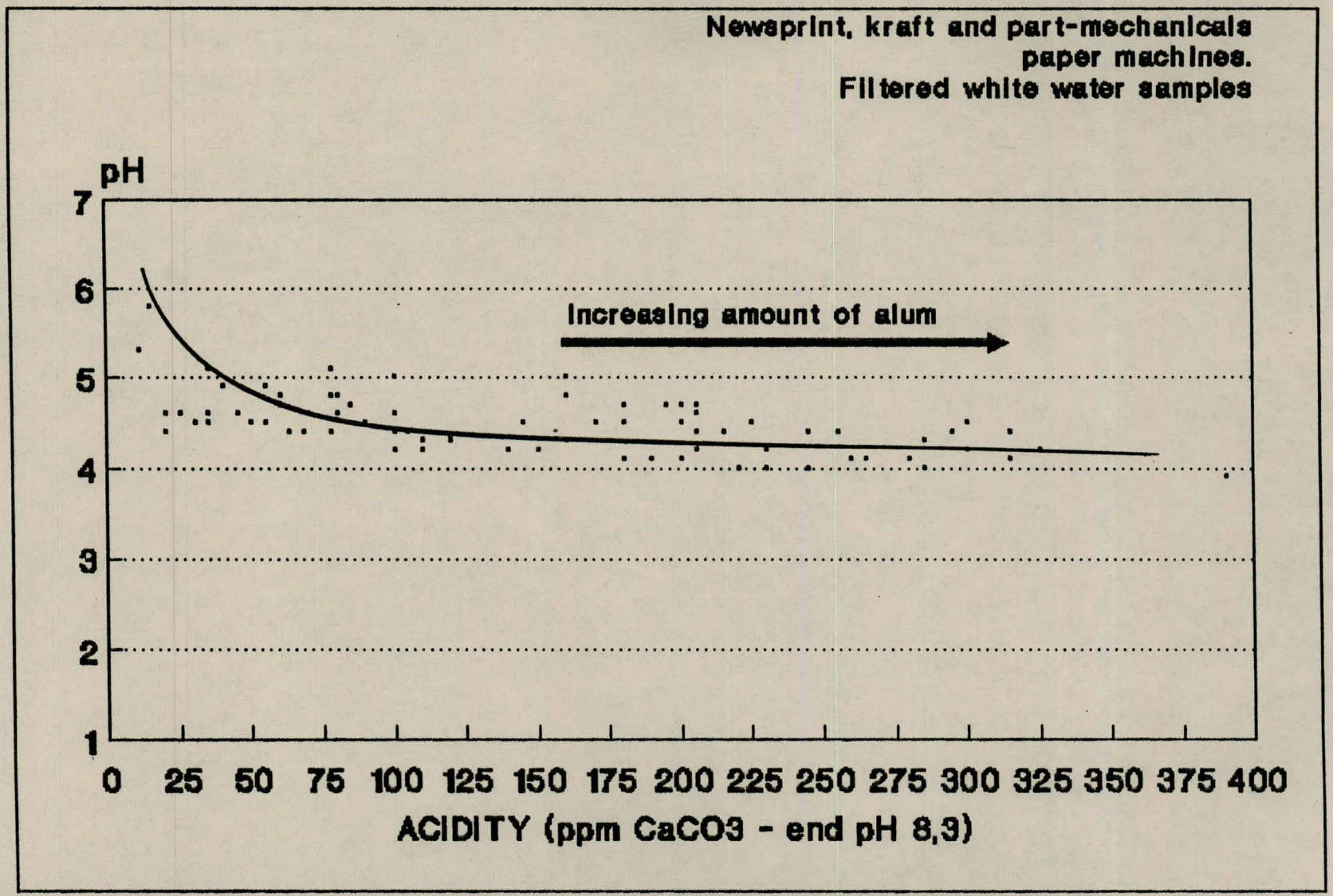


Figure 17 : ACIDITY AND pH INDEPENDENCE for an ALUM based SOLUTION

fundamental parameter in the determination of sizing efficiency. Bar-Lev et al. (1973-1974) developed a titration method to measure and control acidity at the wet end. The control of acidity in the 60-70 ppm CaCO3 range resulted in a lower rosin size usage. Apart from a reduced rosin size usage, other major advantages were quantitatively noticed, i.e. a reduced overall alum usage at the paper machine and an extended felt life at the press section. Other factors which result from control of acidity of the water system and are difficult to quantify in monetary terms:

a) reduced free acidity in the paper, leading to improved resistance to ageing;

b) reduced acidity in the papermachine water system, hence lower corrosion of metal parts;

c) reduced acidity in the mill effluent, resulting in lower alkali demand during neutralization prior to effluent treatment.

3.2.2 On-line Acidity Measurement

An on-line conductivity probe (TBI conductivity probe) was installed in the headbox recirculation pipe (figure 14), and after a few teething problems, it was able to measure the conductivity of the white water in the headbox (figure 18). The acidity and conductivity relationship was then evaluated from the on-line conductivity measurements corrected for variations in headbox pH. These tests were carried out on partly mechanical and wood free grades of paper.

An exponential equation based on the relationship between on-line and laboratory conductivity measurements was fitted to the data:

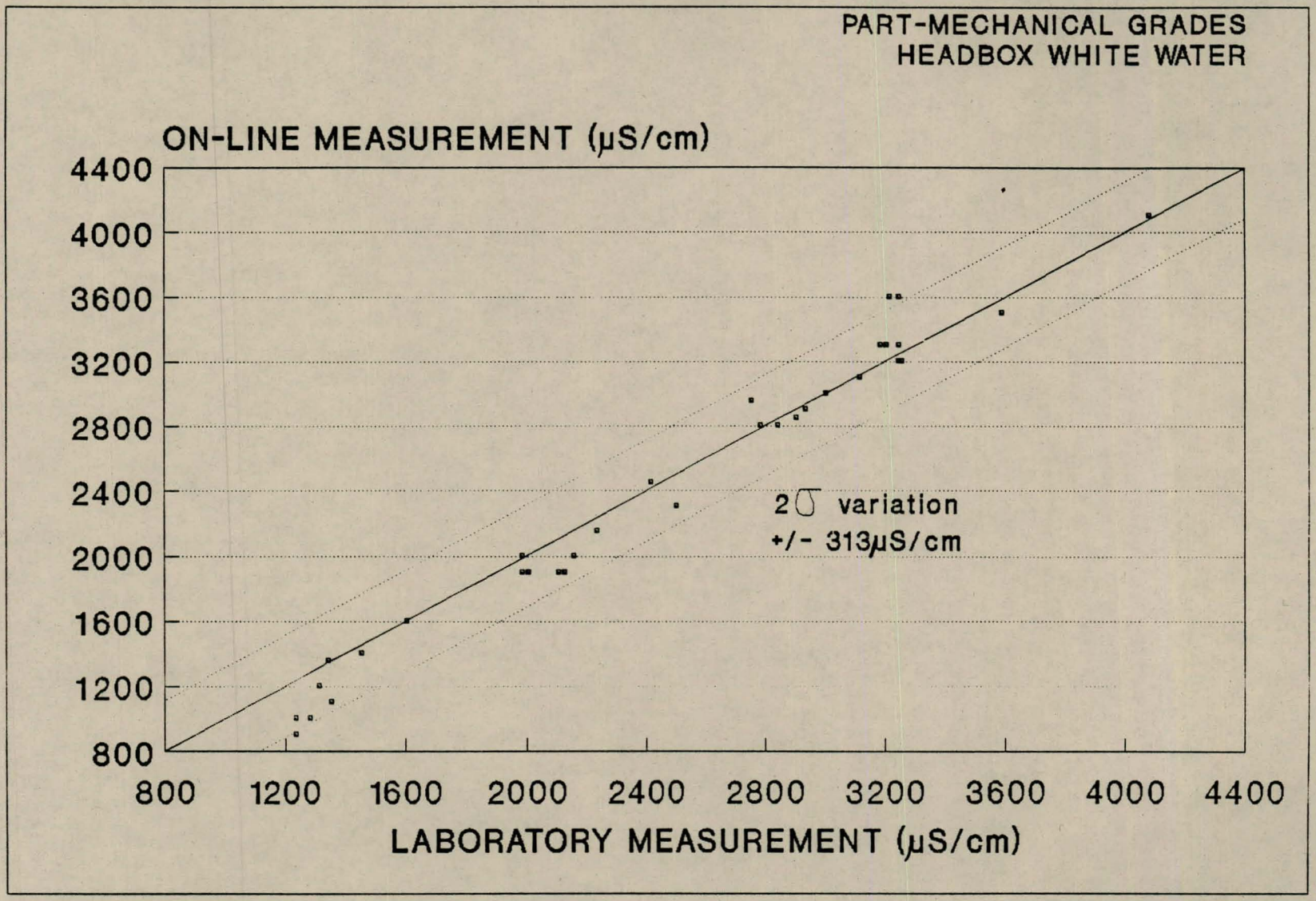


Figure 18 : ON-LINE VERSUS LABORATORY CONDUCTIVITY MEASUREMENTS

Acidity = exp(-1,418 x pH + 0,00125 x Conductivity + 7,835) (1)

with Acidity = acidity (ppm CaCO3 end pH 8,3),
Conductivity = reading on-line probe (μS/cm),
pH = on-line pH measurement.

The 95% confidence limits for the relationship "calculated acidity versus laboratory acidity determination" (figure 19) is 40ppm CaCO3. As the white water acidity increases, the error increases due to the presence of greater concentrations of varying ions in solution. For sizing efficiency and cleaner white water, the acidity of the white water should be below 100 ppm CaCO3 and in this range the correlation is good enough to allow us to use the conductivity measurement method for monitoring and controlling the acidity at the wet end. With improved control within the 150ppm acidity range, it may be possible to further improve the relationship, thereby reducing the error. Care must be taken in using equation 1, as this relationship will be characteristic of the system measured, i.e. dependent on the particular chemistry of the paper machine wet end operation with its pulp furnish, contaminants and chemicals added.

3.2.3 Acidity Control

The conductivity sensor is installed in the headbox recirculation pipe close to the pH sensor (figure 20). The signals from the conductivity and pH probes are fed to a processor which will determine the acidity of the white water from equation 1. The processor will then control the pH at the wet end by addition of sulphuric acid in the blend chest and adjust the acidity in the appropriate range dependent on the

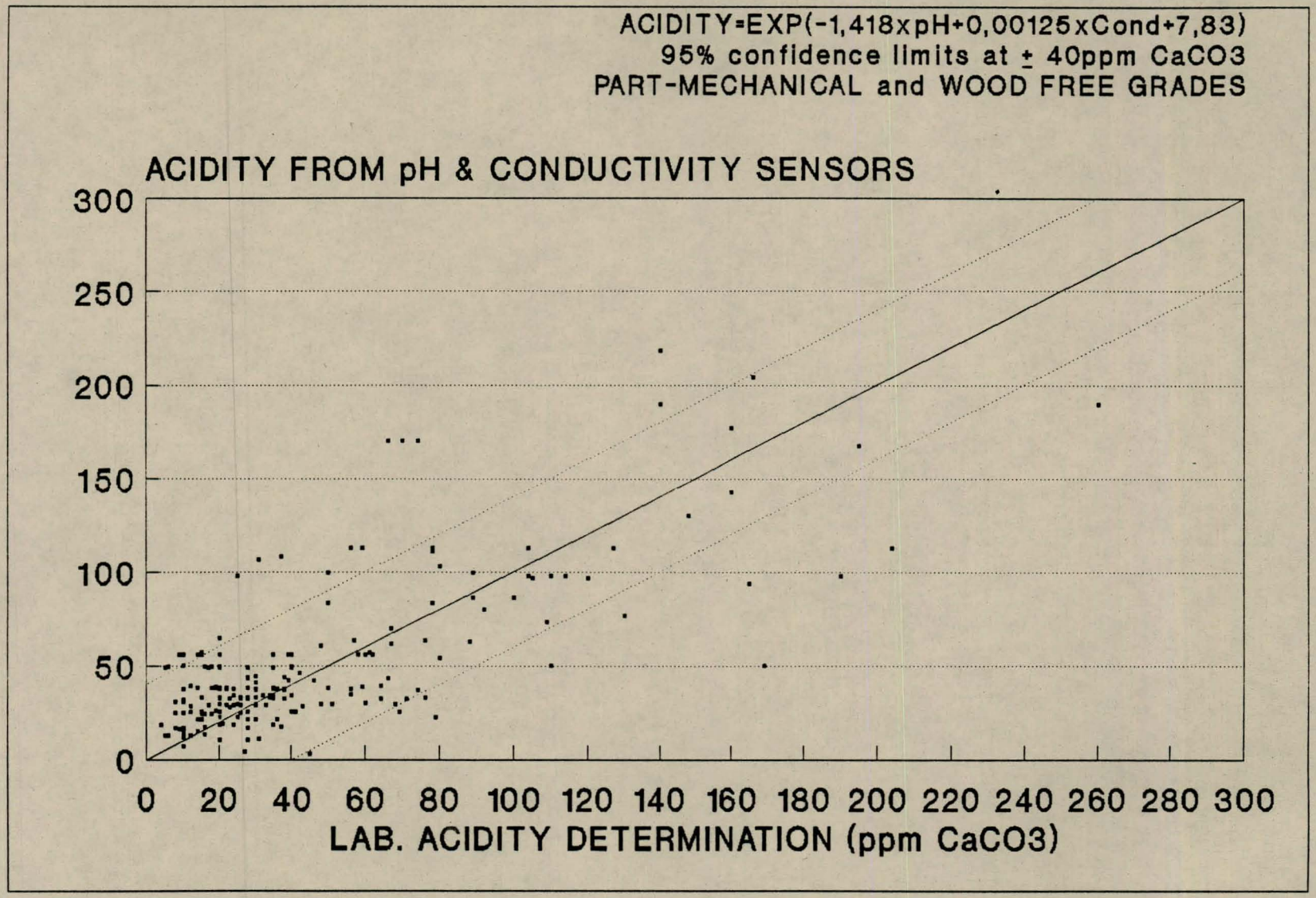


Figure 19 : ACIDITY DETERMINATION FROM ON-LINE pH AND CONDUCTIVITY MEASUREMENTS

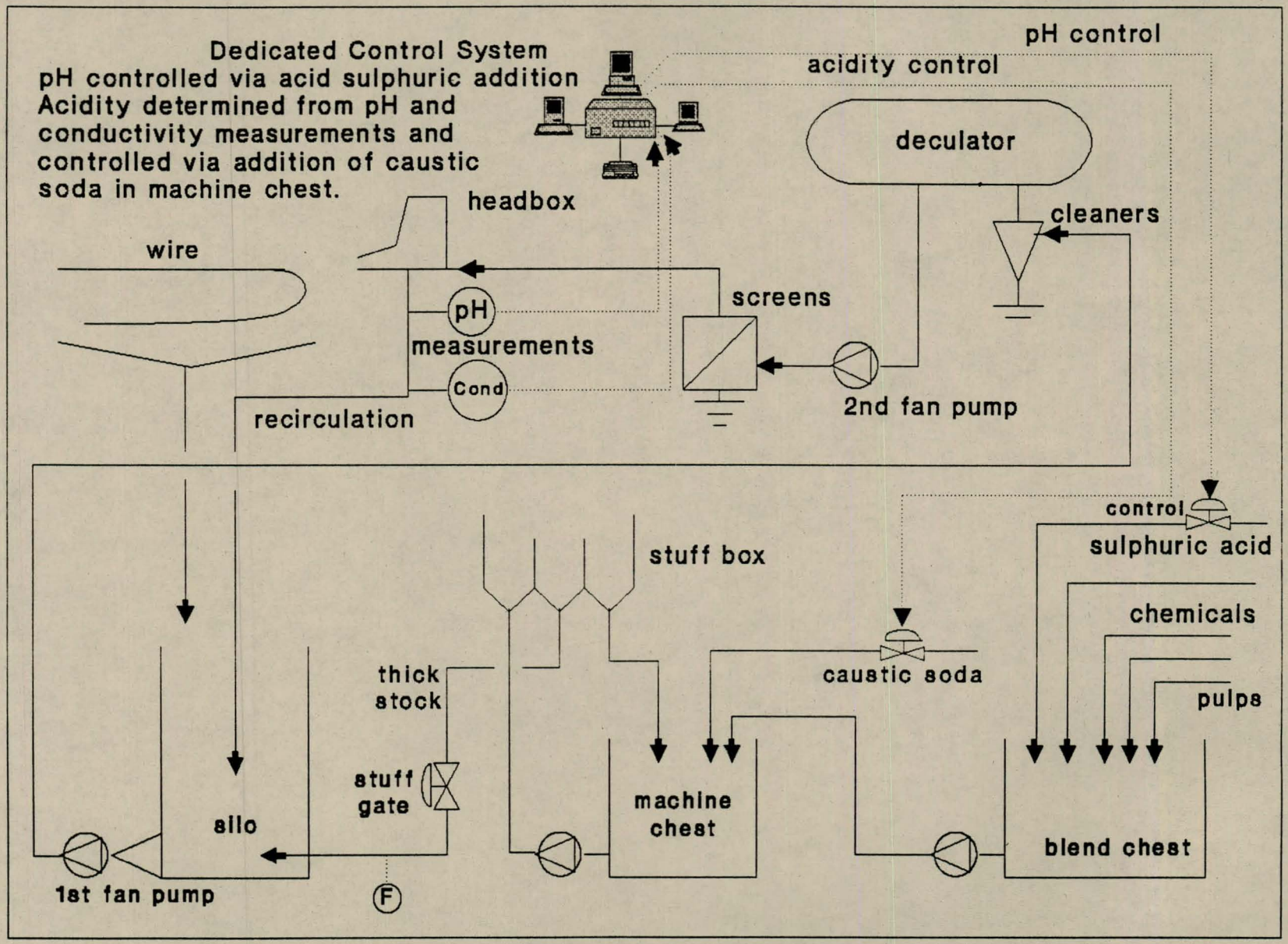


Figure 20 : APPROACH FLOW ACIDITY CONTROL

particular machine wet end chemistry. If the acidity level of the thin stock is below the setpoint value, the caustic control valve will stay close, i.e. the system is clean with a low ions content mainly from contaminants, and will open as the acidity level increases.

3.3 ALUM CONTROL

3.3.1 General

Papermaker's alum, aluminium sulphate, has long been used in the manufacture of paper and paperboard to alleviate paper production difficulties caused by the deposition of wood resin or pitch, or for sizing, pH-value setting, water removal, retention of fillers and auxillaries, etc. One of the main areas of concern is the overusage of alum. The product cost/tonne for alum is not high when seen in context of the overall chemical cost, but this can change in the case where abuse of alum is a common practice. The most common problems associated with the excessive use of alum in acid pH systems include deposits (Porwal et al. 1980), excessive foam, poor retention (Avey 1979, Springer et al. 1982), poor drainage (Sortweel 1972), and poor internal sizing (Bar-lev et al. 1973). Futhermore, odors due to sulphate reducing bacteria, as well as corrosion are also signs of overusage. The diversified chemical activity of the aluminium ion in aqueous solutions (reviewed by Moore et al. 1982) has inhibited the progress of investigation on the interaction of alum with other materials in the paper machine system.

In an acid pH papermaking system the polymeric alumina species available over a narrow and variable pH range, and the early precipitate, are the desired species. Both the polymeric and the charged precipitate species are easily absorbed by the cellulose fibres. The presence of other cationic species in the papermaking system such as cationic starch, cationic organic retention aids, calcium from hard water or organic anionic trash , can shift the chemical balance. In

addition, the presence of dissolved acids (resin acids) and lignosulfonates can increase the cationic demand.

Alum added to the wet end is used in one of the following ways: it is adsorbed onto the furnish substrate, it is chemically precipitated, it is deposited onto the fibre during drying or it goes down the drain. In a controlled system, both adsorption and precipitation will account for the majority of alum used. However in an uncontrolled system, a considerable amount of alum is lost to drain or is allowed to accumulate in the system and "pollute it". A survey of 33 paper machines (Osmerod 1983) adding approximately 1,5% alum to the furnish, reported an average use of 4,5% alum at the headbox, with one machine containing 34% alum. An alum content survey carried out on the paper machines at the Mondi Paper Merebank mill (figure 21) showed variable amounts in the various major streams at the wet end. Control of the alum equilibria becomes more complicated by the close-up of the white-water system. Although the major part of the furnish is made into paper and carried out of the system, a certain amount of soluble matter and fines are retained in the white water, and result in the build-up of dissolved solids in the system. The aluminium ion, with its affinity for the fibre is purged from the system at a more rapid rate than the non-substantive sulphate. Controlling sulphate ion level is important to prevent interference with rosin size efficiency and to increase paper permanence. A small amount of sulfate ions can have a beneficial effect on sizing, because the anionic sulphate tends to moderate the alum-rosin precipitation reaction, resulting in more uniform sizing. High sulphate levels will tie up the available alumina in non-reactive alumina sulphate complexes, thus reducing the amount of alumina that can react with rosin or participate in the

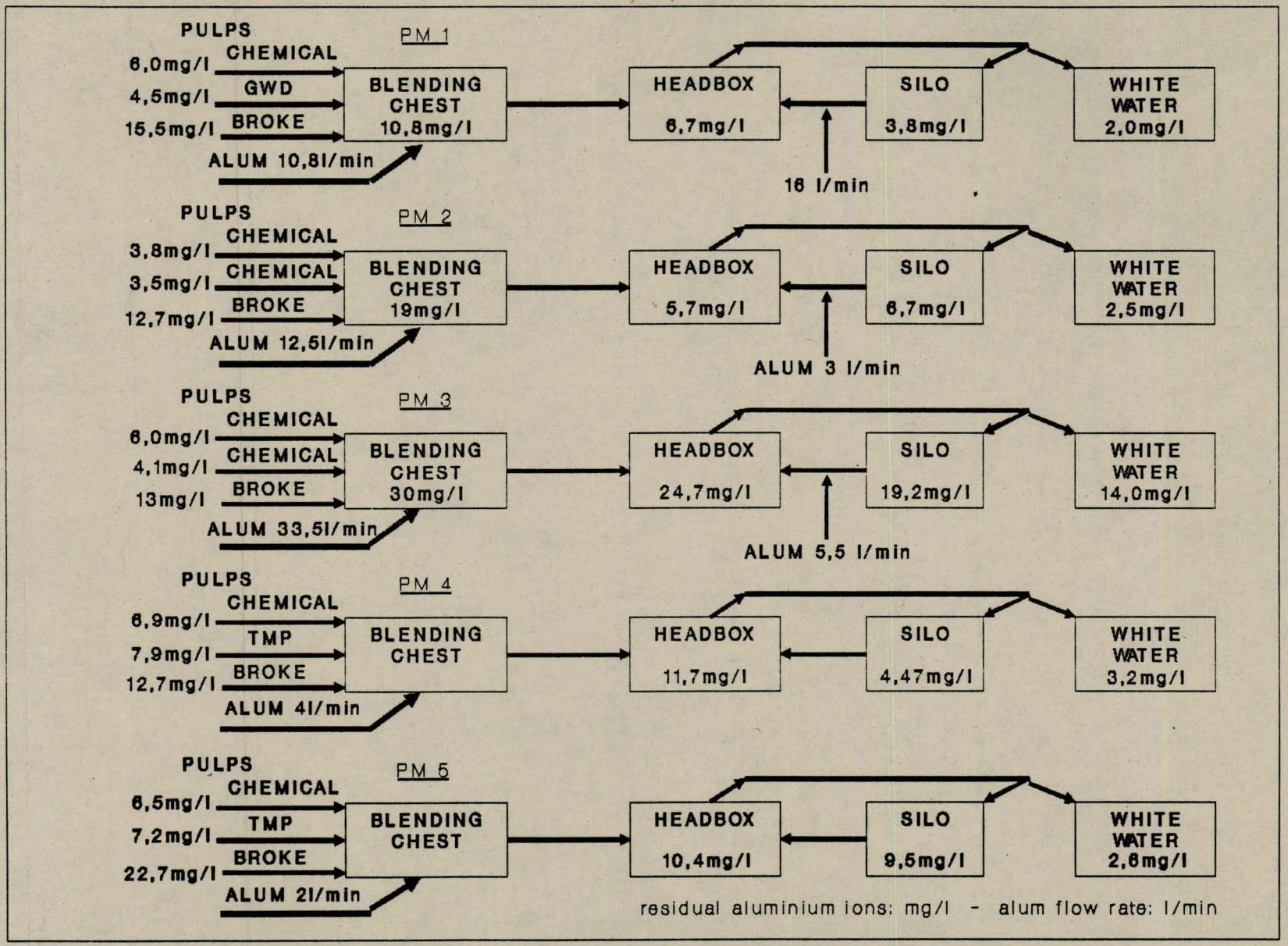


Figure 21 : RESIDUAL ALUMINIUM ION AND ADDITION RATE IN THE MILL

retention mechanisms. Furthermore, as water evaporates in the dryer section, sulphate ion content in the base sheet increases, increasing the sulphuric acid level within the sheet causing a deterioration of the paper with age and also enhancing the tendency of yellowing.

Alkali, such as caustic or soda ash, can be added to increase the pH and allow a higher use of acidic alum. This however will increase the dissolved solids content in the system. Furthermore, increased alum addition will shift the aluminium species distribution to a lower pH.

It is necessary to combine the control of pH, acidity, sizing and alum addition simultaneously. If sizing is not a necessity for the paper grade produced, it is recommended to avoid the use of alum as a retention aid and for acid control. Rather, the papermaker should investigate the use of a special retention aid which will offer increased benefits and ease of usage. However, if paper sizing is required, a control strategy involving various wet end chemistry parameters must be considered.

There is an optimum aluminium ion level for rosin-alum sizing, dependent on the amount of sulphate ion concentration (Springer et al. 1982), with a maximum sizing occuring at a 1:1 ratio of alum to size. However, this amount is dependent on the amount of organic trash present in the system. The sizing of paper will not be discussed and the reader is referred to the literature (Davison 1975, Meaker 1984). There is yet no on-line instrumentation to measure water repellency and the size addition rate is generally set for a specific production run and adjusted and controlled from the dry end laboratory results.

This with other parameters will need to be integrated into the alum addition rate control strategy.

3.3.2 Residual Aluminium Ion Measurement

The fluoride selective electrode technique (Jaselskis et al. 1969) was investigated for use as an on-line method for the measurement of the residual aluminium ion content in the machine water. Total aluminium concentration is quickly and easily determined by potentiometric titration with sodium fluoride and has been used in various laboratory troubleshooting investigations (Homola et al. 1976, Avery 1979). This method has proven to be fast, inexpensive and accurate (Lehto et al. 1981, Govender 1979) and can be easily automated for on-line monitoring of the aluminium residual level.

The sample of water to be tested is mixed with a buffered sodium fluoride solution which complexes the aluminium ions (Govender 1989) and the residual fluoride ions are measured using a fluoride ion selective electrode. The probe reading is then converted back to residual aluminium ion content from a calibration curve (figure 22). Careful consideration should be given to avoid magnetic interferences from the mixer and the ion meter, to insure low levels of ferric, ferrous and calcium ions in the sample (not serious at the prevailing ion concentrations found in the mill) and to ensure a proper sample temperature control during measurement.

At the time of evaluating the method for the proposed control strategy, no automatic analyzer was commercially available and a new instrument (figure 23) had to be built to measure the

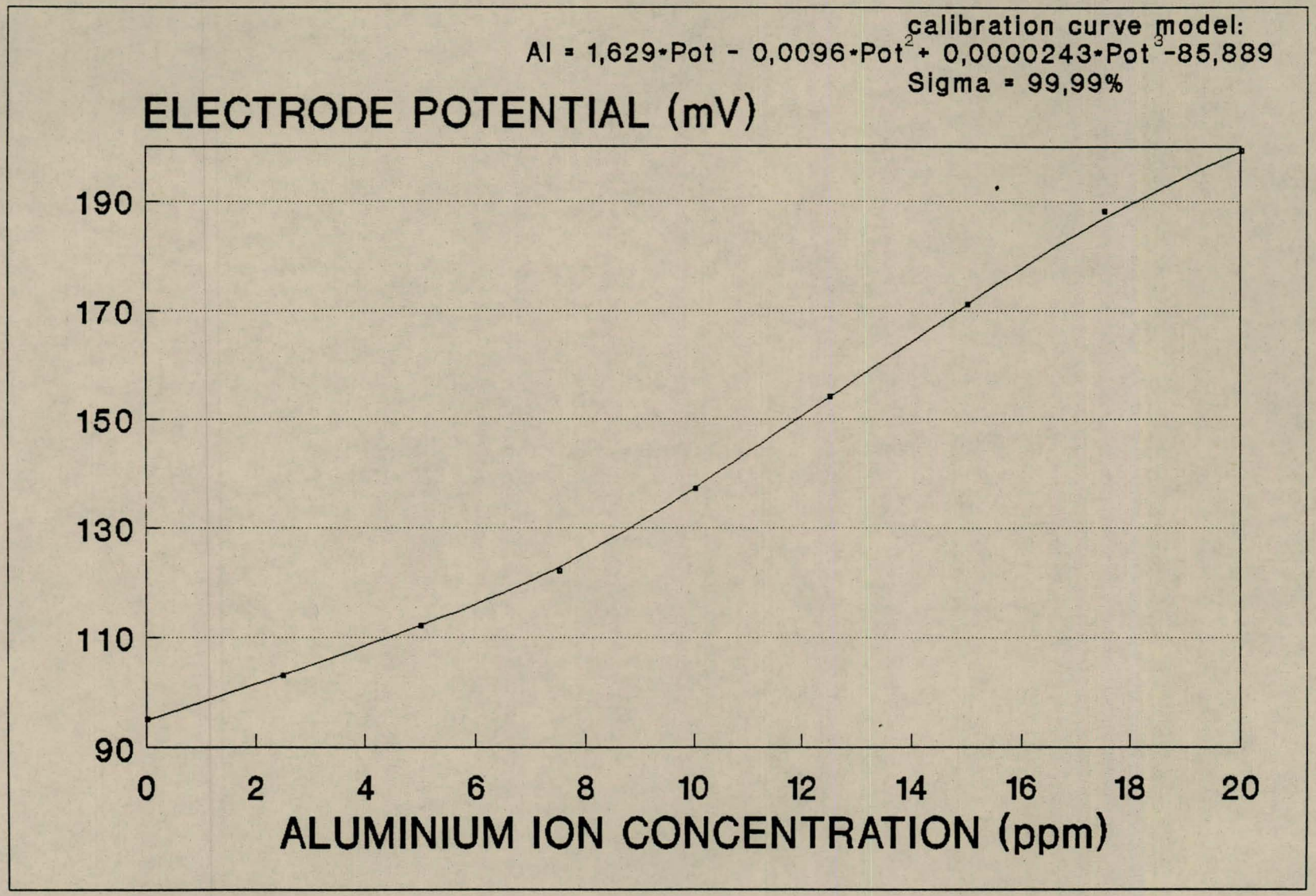
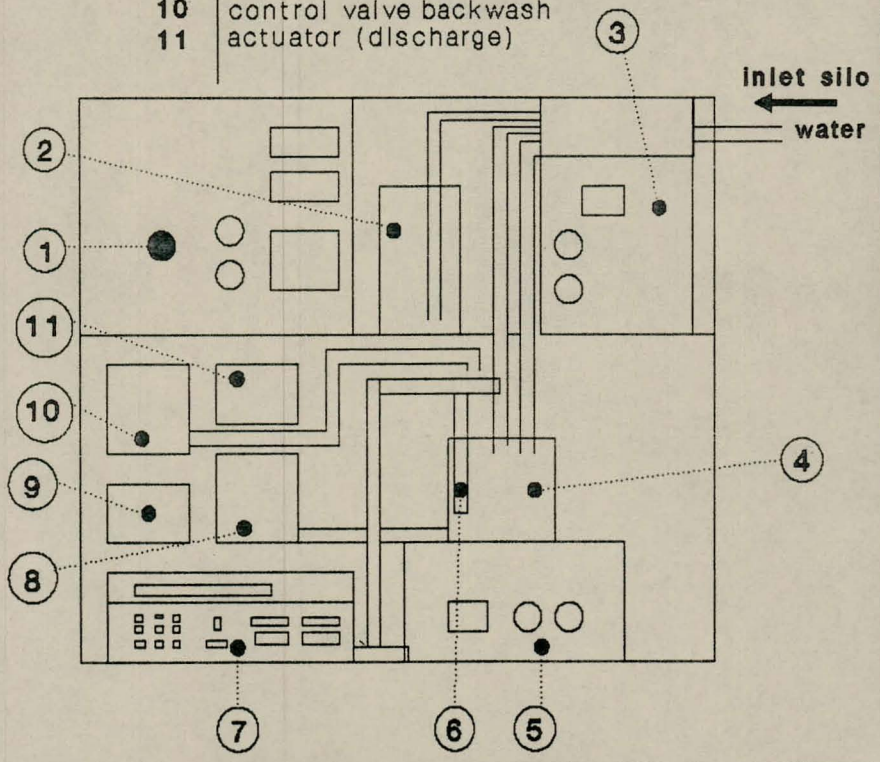


Figure 22 : CALIBRATION CURVE FOR RESIDUAL ALUMINIUM ION DETERMINATION

ref.	instrument
1	PLC
2	fluoride & buffer solution
3	peristaltic pump
4	mixing pot
5	mixer & temperature control
6	fluoride ion selective probe
7	pH/Ion meter
8	control valve (discharge)
9	actuator (backwash)
10	control valve backwash
11	actuator (discharge)



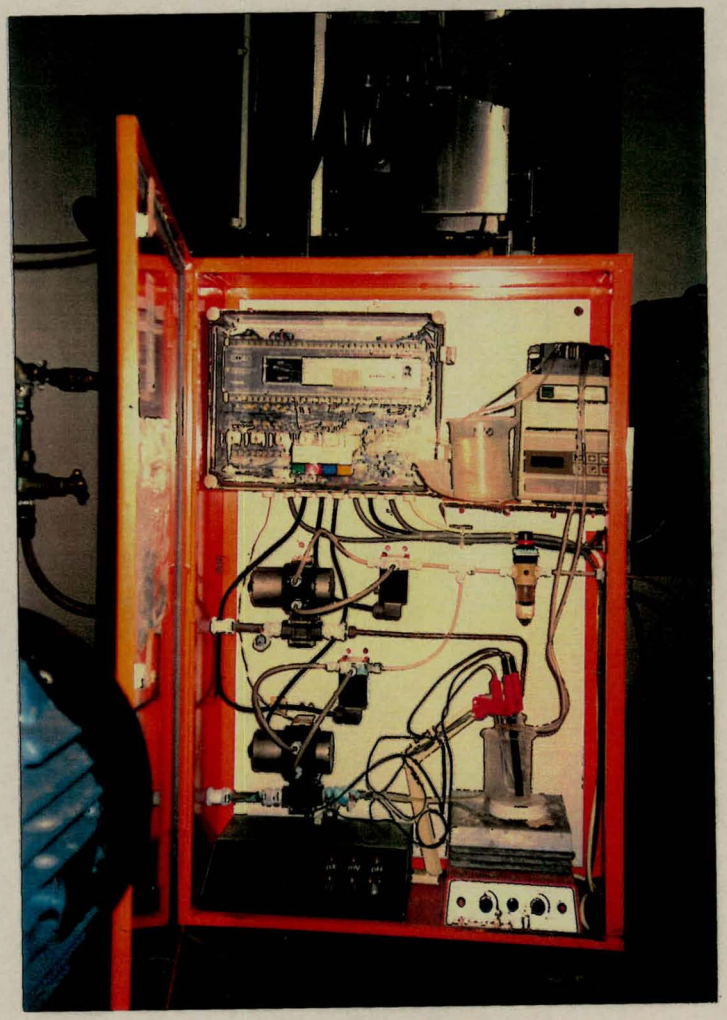


Figure 23 : INSTRUMENT FOR RESIDUAL ALUMINIUM ION MEASUREMENT

residual aluminium ion content in the headbox water. This instrument is similar to the one described by Oehme et al. (1977), but operated without the filtration stages. The sampling is achieved by a 2-stage peristaltic pump, bringing the headbox (or silo) white water and the mixture of sodium fluoride and buffer solution into the mixing chamber. The sample is temperature controlled and well mixed before commencing the residual fluoride ion measurement using the selective probe. The sample chamber is then drained and washed while the reading is converted to residual aluminium ion in the water. The signal can be used for control of the alum addition rate. A similar instrument is now available on the market (Alumat from Kemira).

3.3.3 Alum Control Stategy

Alum levels must be monitored and controlled to alleviate the various problems associated with the overusage of alum, especially in tightly closed white water systems, and to attain optimum paper sizing.

Generally, alum is being added either as a fixed ratio based on paper production rate and rosin size added, or for controlling the pH. However, pH is an inadequate parameter for controlling alum addition. At a low pH, tremenduous amounts of alum might be in the system but in an unavailable state. Such systems will show a very high acidity and a change in pH will be difficult due to the buffering capacity of alum at low pH (figure 17). Paper machines that operate at low pH (3,8-4,2) with high levels of free mineral acidity have stabilized themselves from potential upsets due to pH variation. Although this condition satisfies the papermaker's need to control pH, it

will not create the best environment for sizing and retention.

Size should be added at a point where there is high stock agitation to enhance dispersion and hence uniform blending with the fibres. The higher the stock consistency the better, as alum and size interact with the furnish components in proportion to their respective surface areas and sizing efficiency is also strongly influenced by the amount of fines present and introduced by the dilution white water. Alum adsorption on the fibre, followed by interaction of size with the preadsorbed alum appears to be the basic reaction pathway, i.e. reverse sizing may be more efficient (Marton et al. 1982). Depending on the use of retention aids for cationic demand control further down the wet-end, the amount of alum added should be sufficient to activate the rosin-size and satisfy the cationic demand of anionic contaminants.

The pH of the stock should be set first to a level of $\pm$ 4,7 to attain the optimum aluminium ion species for sizing. Two acids and one alkali were being used for the control, i.e alum, sulphuric acid and caustic. Alum was first added and the amount was controlled by the residual aluminium ion sensor sampling the silo water and determining the residual aluminium ion level (figure 24). Depending on the on-line pH measured in the headbox recirculation pipe, caustic or sulphuric acid was added to attain the optimum process pH setpoint. As the system may buffer itself, acidity control is required. From the conductivity measurement taken on-line in the headbox recirculation pipe and converted back to an acidity value, the addition rate of caustic was controlled.

One of the main problems with this control loop was the volume

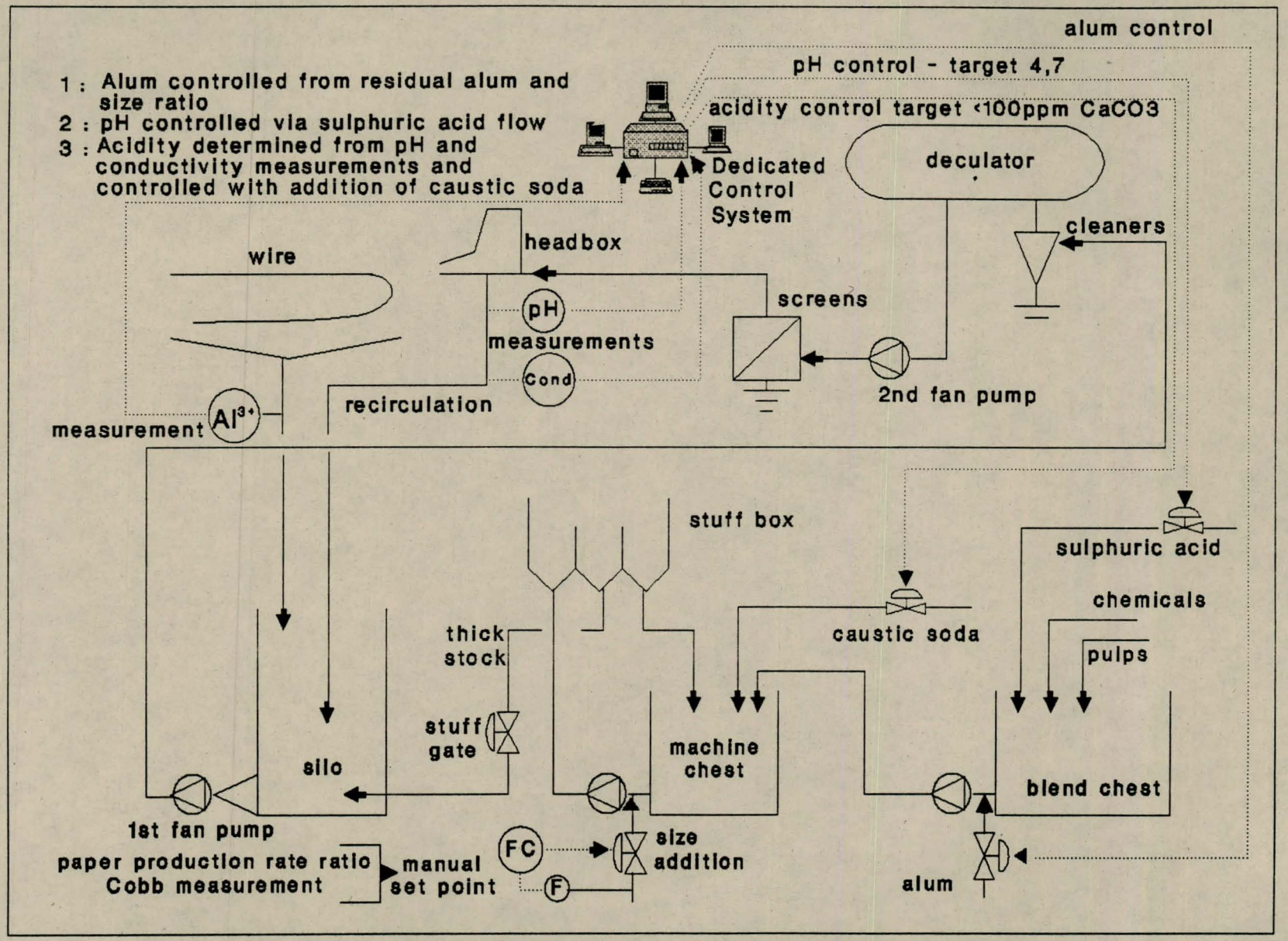


Figure 24 : APPROACH FLOW ALUM CONTROL

of stock and water in circulation, as well as the lag time between the blend chest and the headbox of the paper machine. These will require slow response time for the controller as well as careful timing of sequences for each loop. Another control which must be set in this control loop is related to the break condition at the wet end when the stock is recirculated into the thin stock without being transferred to the wire. The functions of the various loops described above must be frozen. This can be attained by freezing the controllers control actions when a "paper break" condition is reported from the break detectors, and by installing an on-off valve on each chemical line, shutting when the thin stock loop is in recirculation.

3.4 RETENTION

3.4.1 Importance of retention

Retention and its control have attracted increasing attention over the past decade and considerable literature has been published. There are a number of reasons why retention measurement, control and optimization are important.

Stringent effluent guidelines, pressure from environmental groups, reduction of variable costs, limited supply of water, have forced the Pulp & Paper Industry to reuse and close up the water circuit. Attractive cost savings (Franki et al. 1976) were attained. The three dominant factors which control the extent to which water recycling can be practised are thermal energy, dissolved solids and suspended solids build-up.

The increased use of a cheaper furnish, i.e. the use of larger amount of filler, recycled pulp and mechanical fibre, increases the build up of dissolved or suspended solids in the process water, which slowly results in the lower performance with regard to retention and machine runnability (Britt 1977). Dissolved organic and inorganic contaminants will compete with filler and fibres for adsorption of costly chemicals (Scott 1983), (Marton 1980), (Marton et al. 1982-1983). Higher fines content in the furnish has highlighted the need for fines management (Ormerod 1984), (Britt et al. 1985), (Scott 1986) due to the negative influence on drainage as well as retention aid performance (Htun et al. 1978), (Lobber 1977), (Webb 1994). Any fluctuations in the amount of fines will show itself by a change in the two-sidedness of the sheet. However, fines are beneficial for improvements in optical as well as printing properties (Pummer 1973), (Turner 1988).

Poor wet end retention will increase foaming tendencies and sizing problems as well as wire wear. Response to process changes will be slow with longer transition times during grade changes. Furthermore, the performance of the auxillary equipment at the wet end, i.e. saveall, cleaners, will be affected by the increased solids load.

Higher machine speed resulting in increased shear and turbulence has resulted in decreased retention of filler and fines (Marton 1988). To combat this tendency, more chemicals have to be added at various stages to maintain the required level of retention, drainage and sheet formation.

An increased solids load in the back water due to poor retention, will result in an increased solids content in the headbox creating sheet formation problems (Barnes et al. 1989). Very high retention due to excessive flocculation unfortunately can relate to bad formation of the paper (Jokinen et al. 1986).

Retention of fibre and filler in the sheet formation phase is an important parameter for proper papermaking operation. The set target for retention should be relatively high but of even greater importance would be the uniformity of retention.

3.4.2 Retention Formulae

Two parameters are used to measure the retention of fibres and additives on the wire (Smook 1982), i.e.:

$$\text{overall retention} = \frac{\text{amount retained in sheet}}{\text{amount added with stock}} \qquad (2)$$

$$\text{single pass retention} = \frac{\text{amount retained in sheet}}{\text{amount from headbox}} \qquad (3)$$

The economical utilisation of various additives is mainly related to the overall retention, because the portion not retained in the sheet is lost with the white water overflow to drain. However, sheet quality and paper machine operation are more related to single pass retention (Scott 1982).

A mass balance single-pass retention formulae for a Foudrinier or twin-wire machine will require many flows and consistencies to be measured around the wet end of the machine and does not appear to be very practical (Durgueil 1988). There is no universally accepted and applied method of expressing retention. The most common method is a comparison of the headbox and tray consistencies (MacDowell 1974), (Kortelainen 1988), with the assumption that the white water flow is linearly dependent on the headbox flow and the headbox to tray flows ratios are constant, i.e. independent of the white water volume drained from the table. This gives a total solids comparison that could be biased by a change in the ratio of fines to fiber (Britt 1981) as well as a change in the headbox overflow to tray flow ratio, i.e. dependent on the white water volume drained. However, the simple equation, i.e.:

$$\text{single pass retention} = \frac{\text{headbox consistency} - K \cdot \text{silo consistency}}{\text{headbox consistency}} \quad (4)$$

with K,as the coefficient for a paper machine describing the fraction of headbox flow that returns to the silo, has ben used for years by papermakers and gives an indication of the operation of the machine. Caution should be excercised not to compare the retention values of different paper machines without knowing which K-value was used and which paper machine configuration applied. The above equation is only an approximation for the dewatering capacity of a foudrinier table and should not be used

for a twin-wire former.

3.4.3 Instrumentation

The main prerequisite for all automatic control are sensors. Sensors are available (Friman et al. 1988) to measure with good accuracy the solids content in the furnish when just one material is suspended. However, in the headbox or silo white water, various components are present, i.e. fibre, filler, dissolved trash. In the present work, a transmission unit using polarized light (Kajaani LC100 - Kaunonen (1985) - figure 25) was used to measure the headbox and silo total consistencies. Connolly (1987) evaluated the instrument and found an accuracy of $\pm$ 5% over the range 0,2% and 1,5% stock consistency with the filler content having a detrimental effect on the accuracy. For constant filler content, the instrument reading is linear with consistency (Figure 26). However, due to differences in solids content and characteristics of the silo and headbox streams, as well as the furnish characteristics for the various grades (Stein 1987), the calibration of the instrument has to be modified . Figure 27 shows the influence of ash content on the measurement for the same stream consistency and figure 28 the influence of the furnish particle size. The latter was not considered as a variable due to the inability to measure fibre size on-line.

The Kajaani LC-100 low consistency meter will not differentiate between fibres and filler. In order to determine the concentration of a stream independently of the ash content, an additional density meter was installed in serie with the sensor, similar to a study by Lindstrom et al. (1984). However, the error in the measurement was too high (Durgueil 1990), due to the lack of

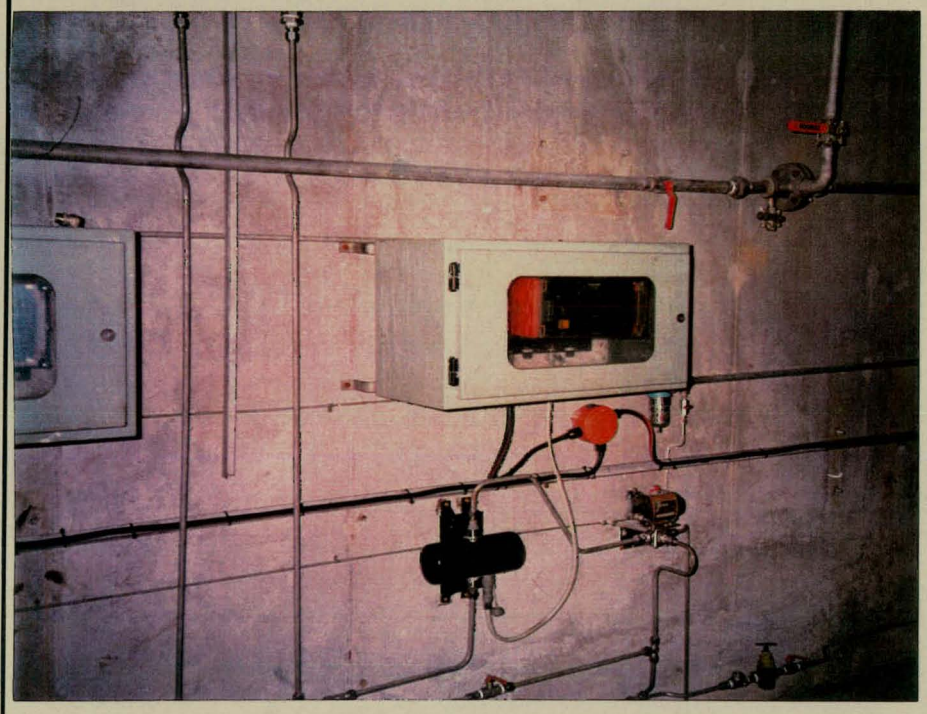


Figure 25 : KAJAANI LC100 LOW CONSISTENCY TRANSMITTER

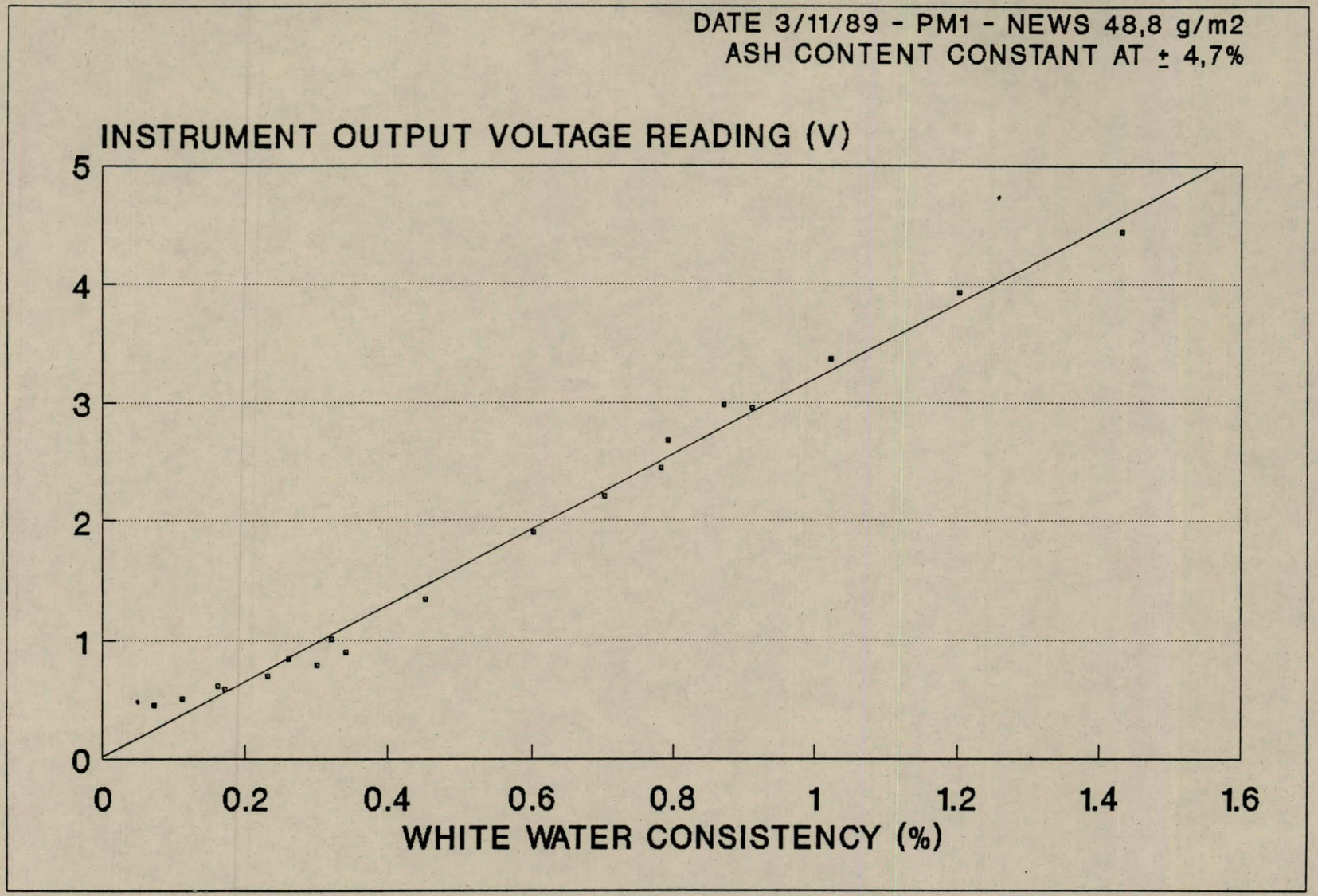


Figure 26 : CALIBRATION CURVE
KAJAANI LC100 vs WHITE WATER CONSISTENCY

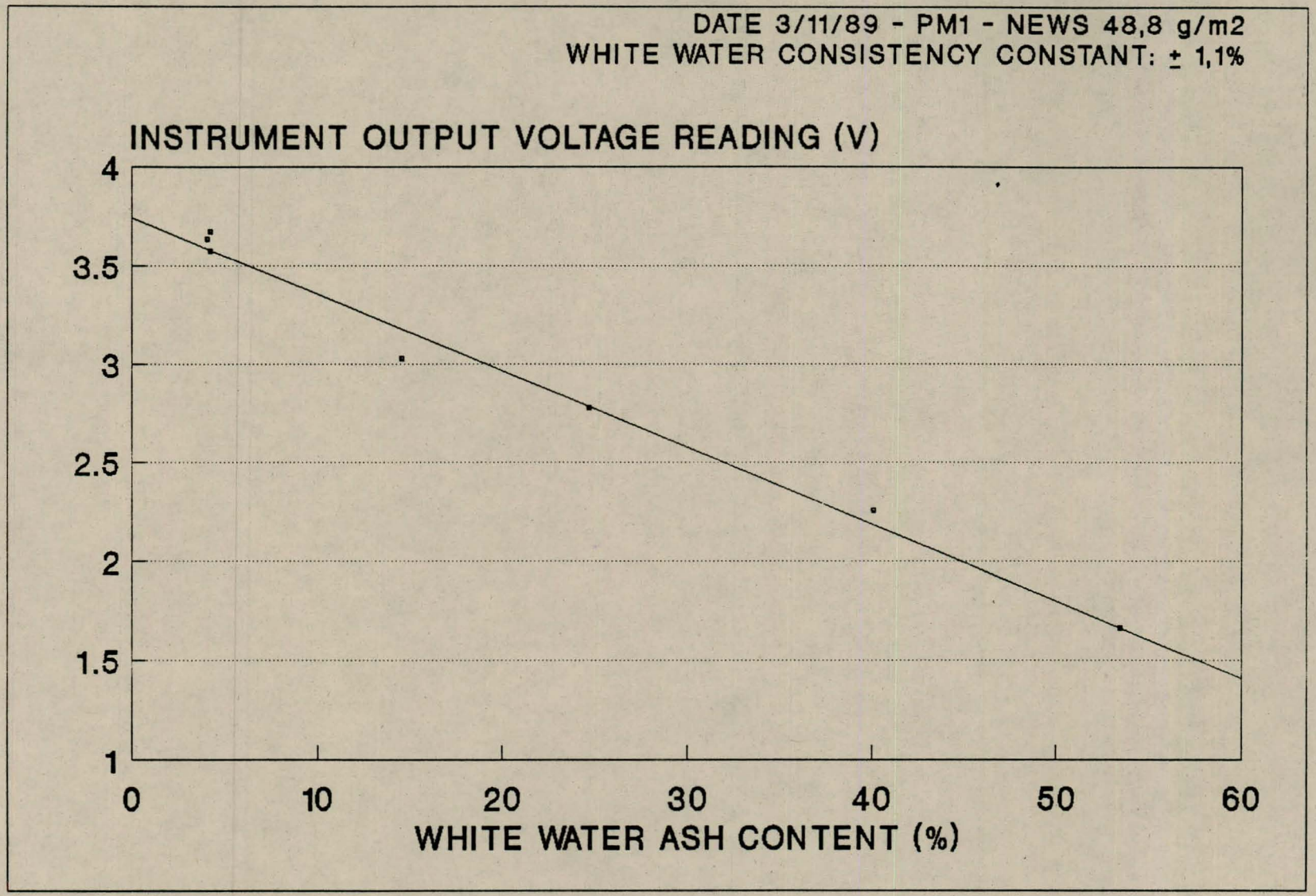


Figure 27 : CALIBRATION CURVE
KAJAANI LC100 vs WHITE WATER ASH CONTENT

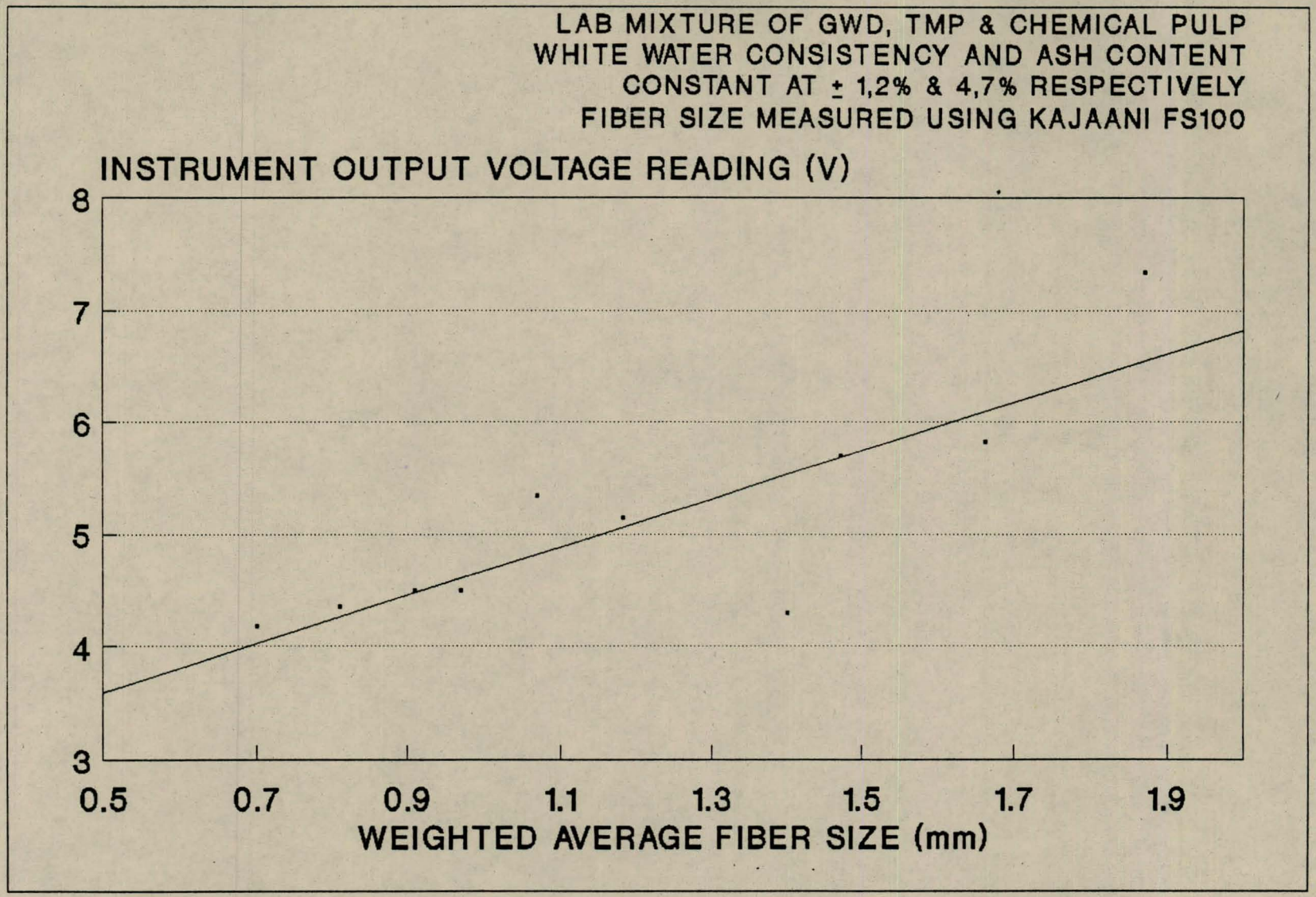


Figure 28 : CALIBRATION CURVE
KAJAANI LC100 versus FIBRE LENGTH

sensitivity of the density meter and pressure-flow variations in the piping reticulation to the instruments. To overcome pressure and flow fluctuations, a small stuffbox was inserted in the system to ensure constant head and therefore constant flow and pressure through the instrument. However this did not resolve the inaccuracy of the density meter and a new approach had to be envisaged.

3.4.4 On-line instrument Installation

Due to the dampening effect of the wet end water volume, retention and consistencies will not change significantly over a period of time (a dye flow change in the primary screen reject tank showed a lag time of ± 3 to 5 minutes). It is therefore possible to use the same instrument for measurement of two streams and averaging the value over a period of time. A timer was then developed which allowed sampling of each stream and backflashing of the unit for a limited time after a certain number of measurements had been made. The signals from the timer were fed to two 3-way valves (figure 29). In between the 3-way inlet valve and the instrument, a stuff box was inserted to insure constant head and flow to the consistency meter. While installed on a twin wire machine, it was decided at this point in time not to include the top wire in the control logic.

The processing of the signal inside the consistency meter was investigated to establish if the accuracy of the measurements could be improved by analysing this signal differently. The polarised light transmitted through the measurement cell was polarised again and divided into two beams (figure 30). One signal with attenuation of light was used for indicating the turbidity of the white water and the other signal, as an indication

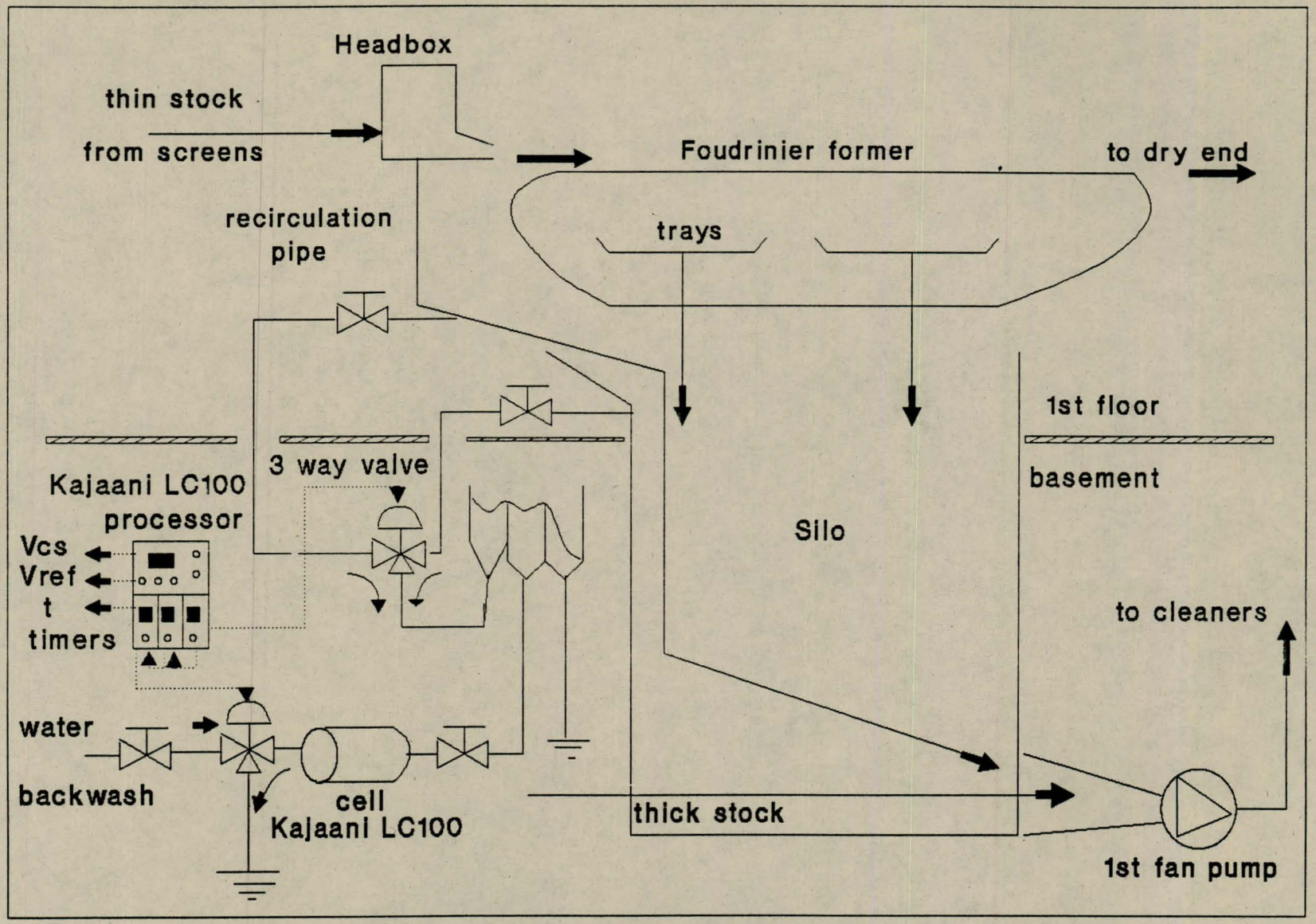


Figure 29 : CONSISTENCY METER INSTALLATION

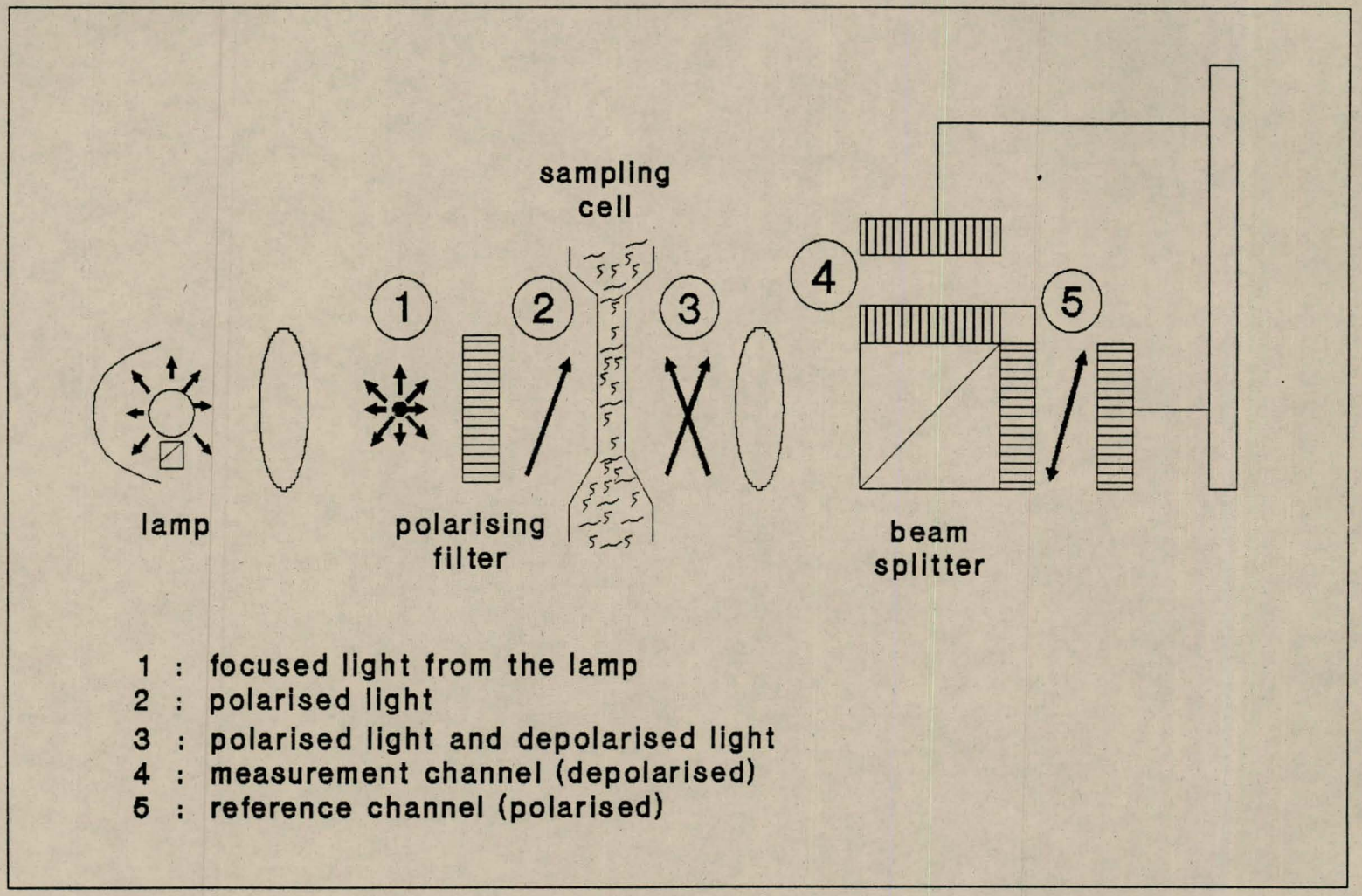


Figure 30 : MEASUREMENT PRINCIPLE OF KAJAANI LC100 CONSISTENCY TRANSMITTER

of the depolarization due to the presence of fibres. These two signals are mathematically and electronically manipulated by the consistency meter to give one output signal referred as Vcs by:

$$Vcs = \frac{10 \times Vm}{Vref} \qquad (5)$$

with Vm : measurement channel signal (Kajaani units);
Vref: reference signal (Kajaani units);
Vcs : output signal (Kajaani units).

These two signals were then monitored on-line via gathering the reference signal measurement (Vref - Kajaani LC100 terminology) and the output signal measurement refered as Vcs for headbox and silo white water over a wide variety of grades and furnishes (table 2). From the results, regression analysis were performed to correlate the wet-end variables with the two internal signals of the Kajaani LC100 low consistency transmitter.

3.4.4.1 Consistency determination

A regression analysis was carried out predicting the white water consistency (figure 31) from the two signals of the consistency meter:

$$C = 766{,}8094 \times \frac{1}{Vref} + 0{,}101119 \times Vcs - 0{,}19975 \qquad (6)$$

with C : total sample consistency (%);
Vref : unpolarised signal (Kajaani units);
Vcs : polarised signal and modified via Kajaani processor (Kajaani units).

Table 2 : PAPER FURNISH DURING KAJAANI LC100 EVALUATION

Date	Paper Grade	Furnish (%)			Filler (ml/min)
		L/F	S/F	GWD	
10/7/92	Text 60g/m2	35	0	65	20
21/8/92	Text 60g/m2	38	0	62	3
24/8/92	Text 60g/m2	36	0	64	27
14/9/92	Text 60g/m2	40	0	60	23
15/7/92	Tablet 65g/m2	40	50	10	36
15/7/92	Tablet 65g/m2	35	95	10	46
15/7/92	Tablet 65g/m2	35	95	10	36
17/7/92	Tablet 58g/m2	40	50	10	17
20/7/92	Tablet 58g/m2	38	52	10	20
21/7/92	Tablet 58g/m2	38	52	10	20
22/7/92	Tablet 58g/m2	38	52	10	15
31/7/92	Tablet 58g/m2	36	54	10	17
12/8/92	Tablet 58g/m2	45	45	10	23
13/8/92	Tablet 58g/m2	40	50	10	16
2/9/92	Tablet 58g/m2	40	50	10	19
23/7/92	Bond 80g/m2	35	65	0	67
27/7/92	Tablet 46g/m2	45	45	10	25
5/8/92	Tablet 46g/m2	45	45	10	7
11/8/92	Tablet 46g/m2	45	45	10	18
11/9/92	Tablet 46g/m2	45	45	10	20
3/8/92	Script 58g/m2	40	54	6	20
3/8/92	Script 58g/m2	40	52	8	20
3/8/92	Script 58g/m2	45	55	0	17
6/8/92	Manuscript 60g/m2	40	50	10	16
7/8/92	Manuscript 60g/m2	40	50	10	17
31/8/92	Manuscript 60g/m2	44	0	56	32
1/9/92	Manuscript 60g/m2	46	0	54	28
14/8/92	Tablet 70g/m2	37	53	10	33
18/8/92	Bank 46g/m2	42	58	0	26
19/8/92	Bank 46g/m2	44	56	0	25
3/9/92	Xerox 80g/m2	23	77	0	89
8/9/92	Wove 70g/m2	25	27	48	11
9/9/92	Wove 70g/m2	25	27	48	11

L/F : long fibre chemical pulp
S/F : short fibre chemical pulp
GWD : groundwood pulp
Filler : clay

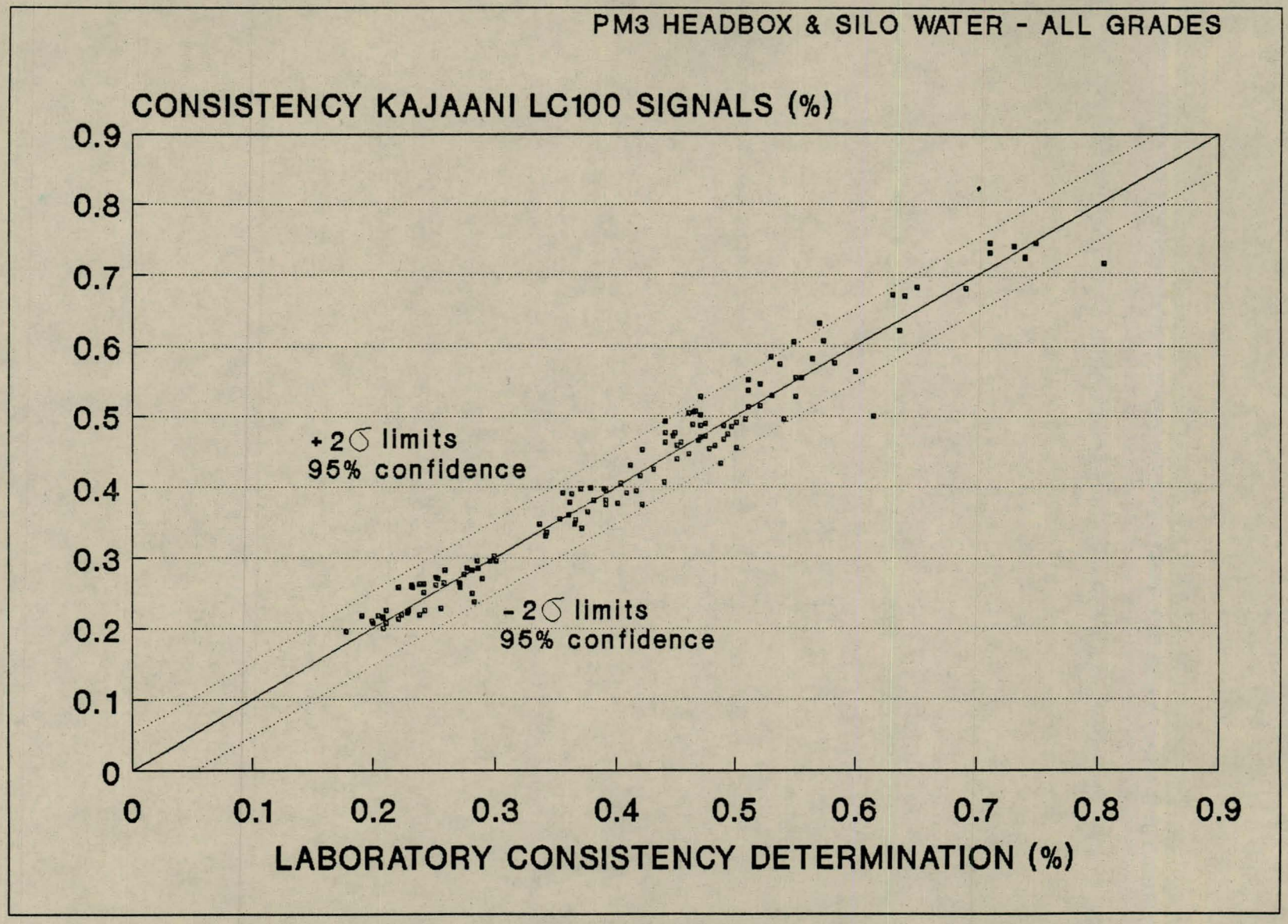


Figure 31 : CONSISTENCY MEASUREMENT USING KAJAANI LC100

The regression coefficient (R2) was 0,965 and the standard error for the estimate (σ) amounted to 0,026. The results obtained gave proof that the processing of the Kajaani LC100 signals could be done in a different way to determine the concentration of the silo and headbox streams independently of the fiber type (part-mechanical and wood free) and ash content.

The above correlation is in accordance with the light polarization effect of the fibres present in the stream, i.e. Vref representing the increase in the stream turbidity with a reduction of the polarised light received and Vcs representing the gain in polarisation due to the increase amount of fibre present. Total stream consistency (from equation 6) may be determined differently by manipulating the signals received in other ways and equation 6 is not based on any scientific theories.

3.4.4.2 Ash content determination

The same procedure was carried out for the determination of the ash content of the stream (figure 32):

$$\text{Total Ash} = -1{,}005 \times Vm - 0{,}565 \times Vref + 2315{,}519 \qquad (7)$$

with Total Ash = Ash x C x 100 (ppm) = ash content of sample tested;

Ash = ash content as a percentage of the solids present (%);

C = total sample consistency (%);

Vm = measurement channel signal (Kajaani units);

Vref = unpolarised signal (Kajaani units).

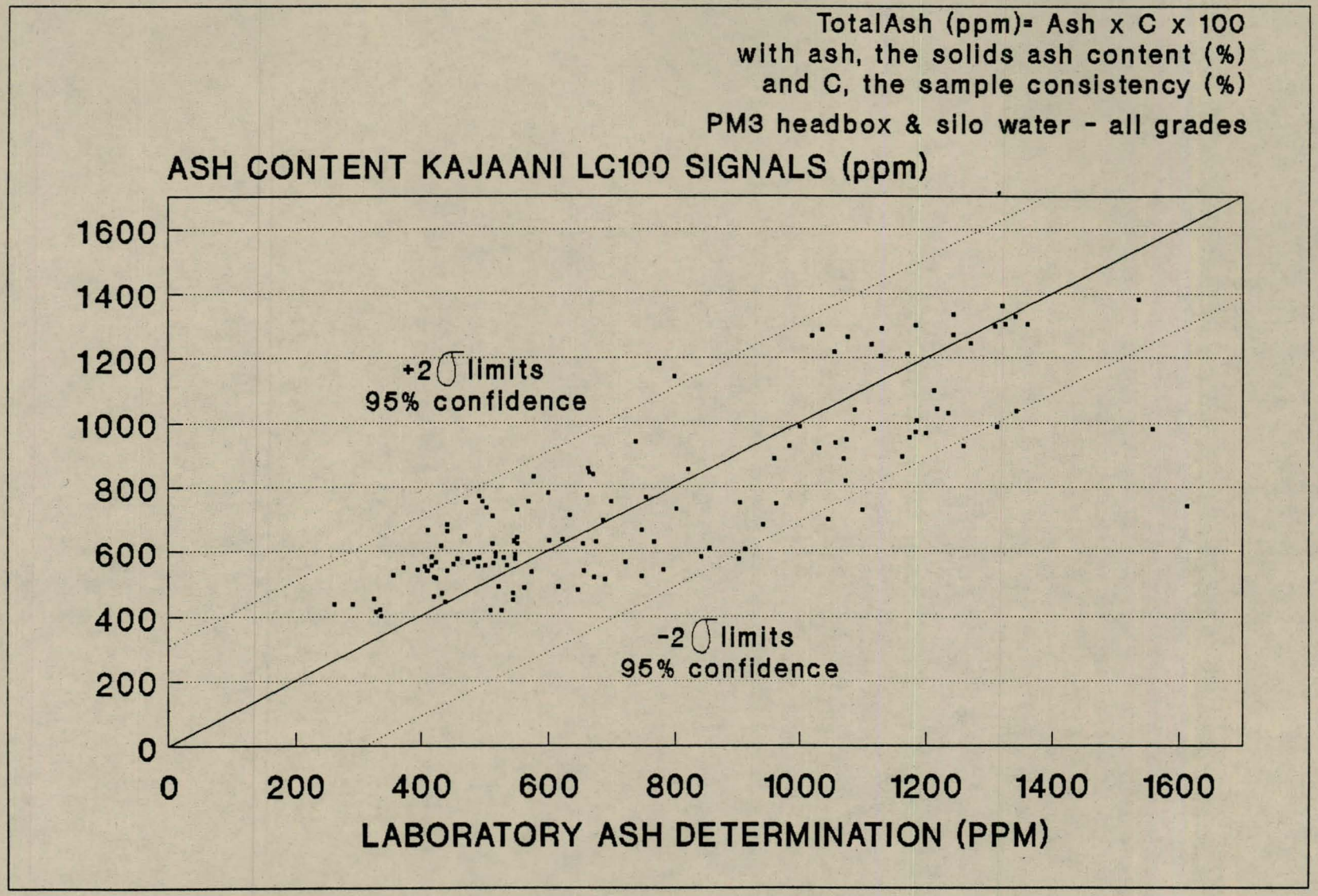


Figure 32 : TOTAL ASH MEASUREMENT USING KAJAANI LC100

The regression coefficient (R2) is 0,67 and the standard error for the estimate (σ) is 155ppm.

The solids ash content was then determined from equations 6 and 7 (figure 33) and the standard error for the estimate (σ) is 1,75%.

The ash content measurement procedure in the laboratory was checked to determine the range of error in the measurement (figure 34). As the addition rate increased, the error increased as the losses during ignition increased. The "standard deviation" in the laboratory measurement is 211ppm and similar to the range of error found using the above procedure for the total ash content measurement. Therefore, unless the laboratory procedure is improved, it will be difficult to reduce the error which will be encountered in the above procedure as the comparison and reference is based on the laboratory results.

3.4.4.3 Total first pass retention

From the calculated values via equation 6 and the laboratory data, the first pass retention values (using equation 4 with K=0,9) were compared to determine the range of error (figure 35) in the determination of first pass retention using the Kajaani LC100 as the instrument. The 95% confidence limit is 6%, i.e. each determination of first pass retention using the above method will be within 6% maximum of the laboratory result.

3.4.4.4 Ash retention

The same as above was carried out for the first pass ash retention (figure 36) using the equation:

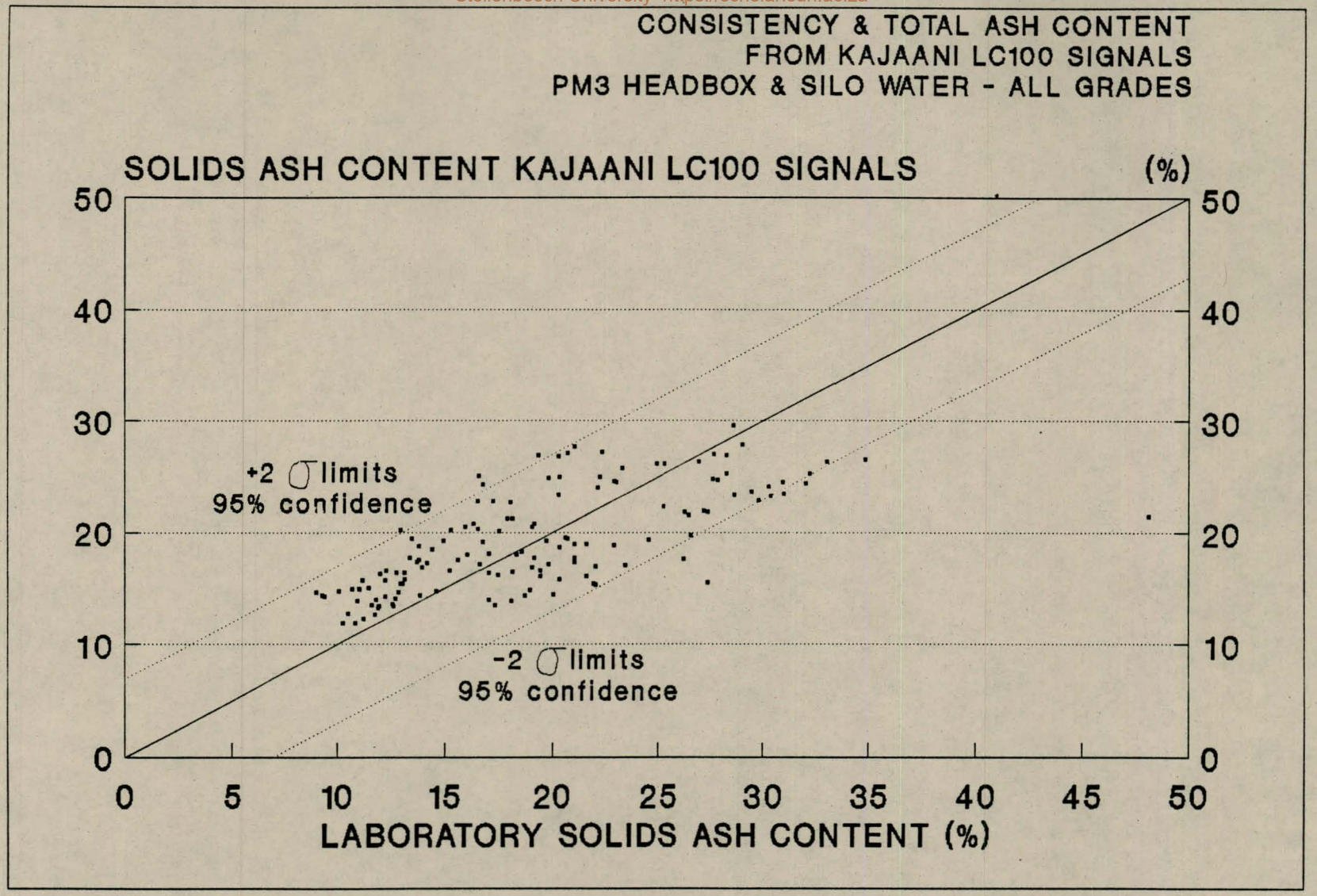


Figure 33 : SOLIDS ASH CONTENT
USING KAJAANI LC100

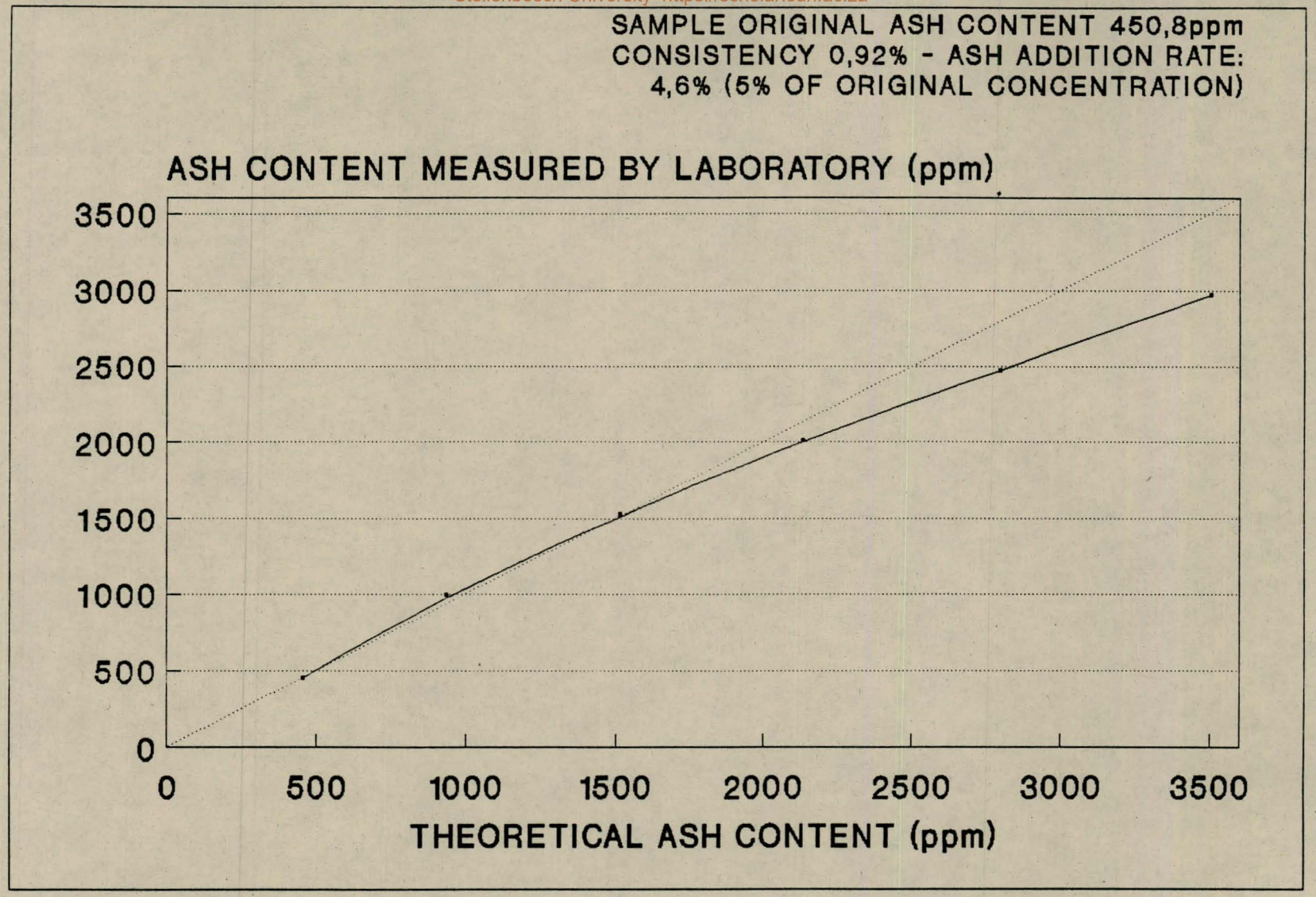


Figure 34 : LABORATORY ASH DETERMINATION ERROR

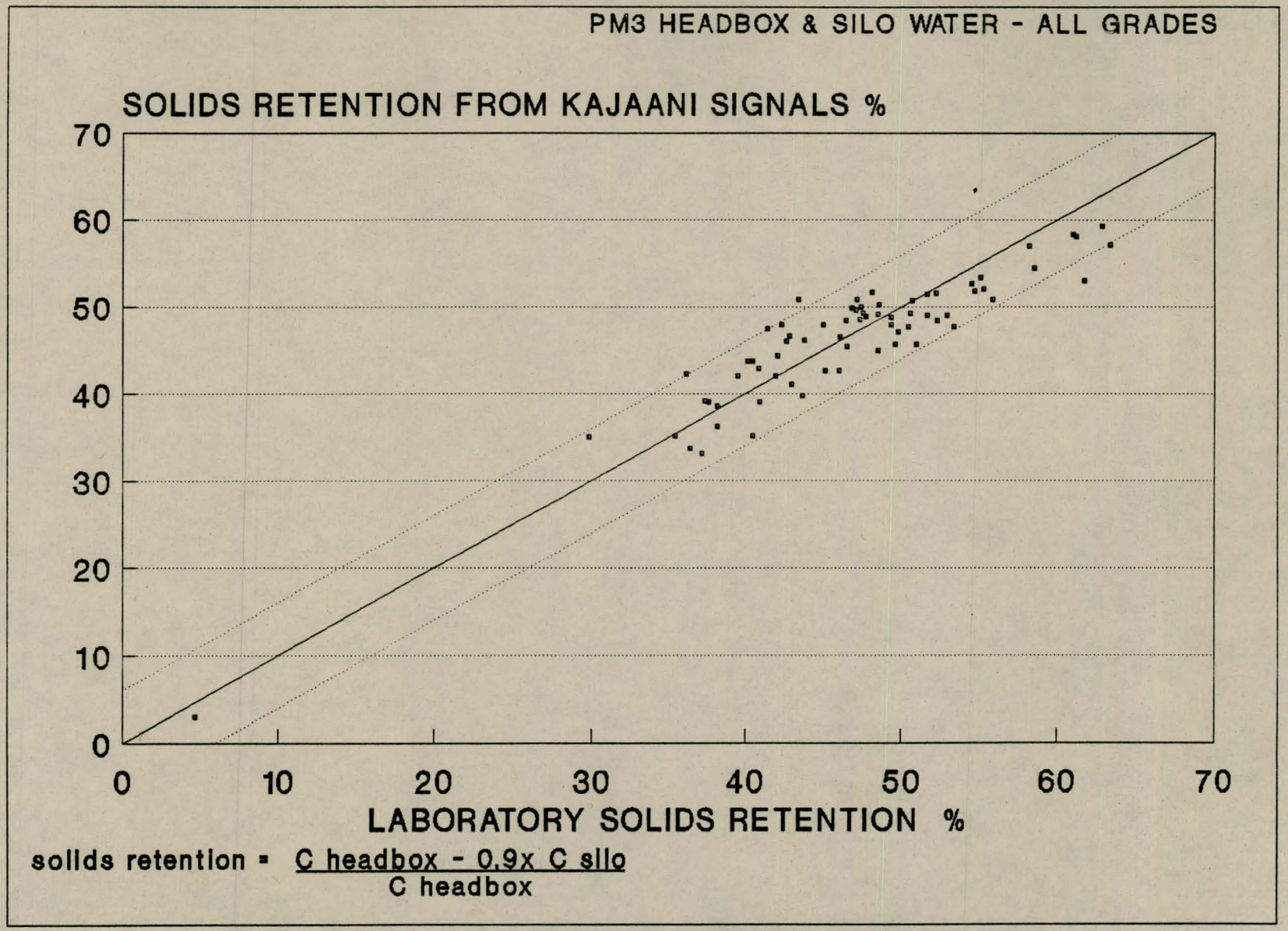


Figure 35 : SOLIDS RETENTION
KAJAANI LC100 RESULTS vs LABORATORY DATA

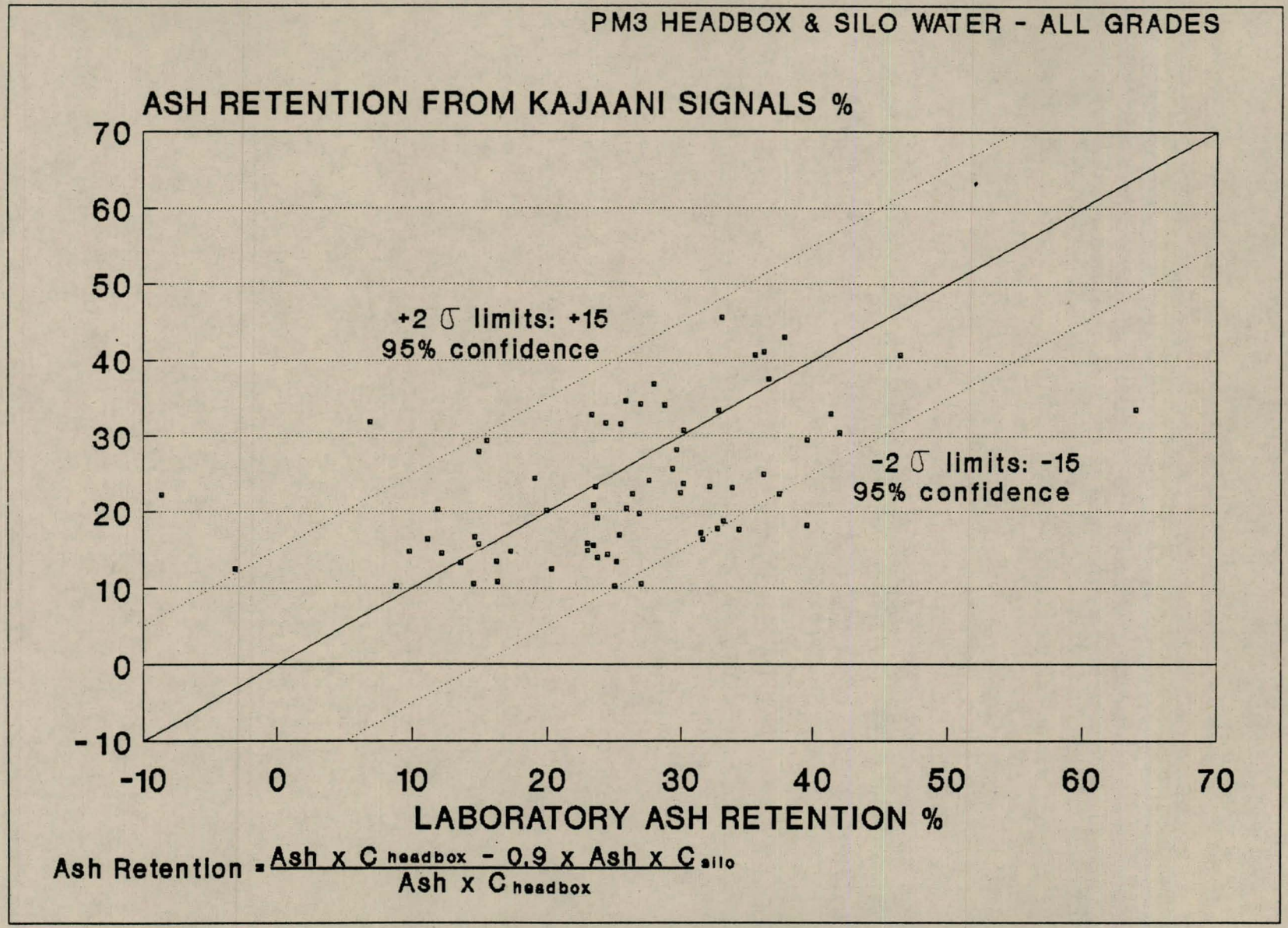


Figure 36 : ASH RETENTION
KAJAANI LC100 RESULTS vs LABORATORY DATA

$$\text{Ash retention} = \frac{(\text{Ash x C})\text{headbox} - 0{,}9\text{X}(\text{Ash x C})\text{silox}100}{(\text{Ash x C})\text{headbox}} \quad (8)$$

with C = sample solids concentration (%);
Ash = solids ash content (%);

and ash retention expressed in percentage. The 95% confidence limit is 15%.

3.4.4.5 Conclusion

From the results obtained with the proposed method for the measurement of solids and ash content of a fibrous stream using the Kajaani LC100 low consistency transmitter, it can be said that total solids content as well as first pass retention values are well in accordance with the results from the laboratory and the instrument can be used on-line for process control. The results for ash content and ash retention are acceptable but further work is recommended to improve the measurement method and therefore, reduce the range of error in the determination.

3.4.5 Retention control

Controlling retention is complicated. Retention is affected by several controlled and uncontrolled variables of the paper machine (Scott 1983). The control scheme in which more chemical is added to the system when the measurement is lower than the set point does not work with complex chemical systems. The retention level will fluctuate depending on the paper grade produced as well as changes in the headbox furnish and headbox settings. Futhermore, retention is not the only parameter to take into account and a combination of retention,

drainage and formation values must be considered.

A clear strategy of separating the control of fibre flocculation from the control of fines has arisen (Britt 1981, Rahman 1987) due to the different mechanisms of attraction involved. There is an interdependence between chemical and mechanical forces occuring in a stock suspension before the headbox. Generally, the papermaker controls sheet formation by modifying headbox consistency. This will lead to reducing macroflocculation in the headbox approach flow by increasing shear and turbulences due to the increased volume of water in circulation without affecting the microflocculation of the fines and fillers onto the fibre. However, passed a certain level of turbulence, this microflocculation will be destroyed resulting in a loss in retention of fines and drainage problems.

Generally, the papermaker controls the amount of retention aid to the paper production rate or amount of fibrous stock added. This approach is based on "trial-and-error" experience and does not take into account upsets at the wet end. Stein (1987) and Nokelainen et al. advocated a simple retention control by keeping constant the solids content of the white water and adjusting the flow of retention aid. This approach leads to improved retention and drainage on the machine with reduced chemical costs in a narrow range of chemical variable equilibrium and cannot take into account process upsets. Lindstrom et al. (1984) proposed to interface colloidal titration measurement of the pulp furnish with the retention measurement system and so by, control the addition of retention aid. This control system allows to take into account changes in the stock preparation area and its variable influence on particle surface charge. The retention aid control loop is able to establish if

retention aid dosage should be increased or decreased. Scott (1983) recommended a control strategy based on the control of interfering substances in the thick stock using cationic demand control and control of first pass retention within the headbox approach flow. Springer et al. (1985) went further by introducing a third loop which could monitor the filler retention in both the final sheet and in the recycled broke recovery system.

The control strategy for retention has to take into consideration the electrokinetic properties of the fibre furnish. Each installation will adapt to a particular paper machine due to the various combinations of chemical additives that the papermaker has at its disposal, i.e. from alum as in the past to coagulant and flocculant programs of various chemical suppliers. In the chapter dealing with the "Overall Chemical Control Strategy", a retention control loop based on the strategy of neutralization of dissolved interfering substances (cataionic demand) in the thick stock will be illustrated. Also the control of the 1st pass retention within the thin stock loop of the papermachine using a coagulant (for microflocculation) and a flocculant (for macroflocculation) will be discussed in this chapter.

3.5 ELECTROKINETIC MEASUREMENT

3.5.1 General

The electrokinetic properties (or more popularly referred to as the zeta potential) of the furnish components have been assumed in recent years to be important parameters in the papermaking process. These parameters have been reported to be controlling factors in the retention of pigment dyes, in internal sizing, wet strength resin application, during drainage and for the application of flocculants in savealls.

Virtually all materials become electrically charged when placed in water. This can be the result of groups on the surface (e.g. carboxyl or sulphonic acid), specific adsorption of ions from solutions, or isomorphous lattice substitution (e.g. clays). A colloidal particle (e.g. fibre, fine or filler) suspended in a papermaking stock is surrounded by a dense layer of ions having a specific electrical charge. This layer is surrounded by another layer, more diffuse than the first, which has an electrical charge of its own. The bulk of the suspended liquid also has its own electrical charge. The difference in electrical charge between the dense layer of ions surrounding the particle and the bulk of the suspended fluid is the "zeta potential". By causing relative motion between the particle (with its immobile ions and solvent) and the bulk of the solution, a potential is generated which can be measured and related to zeta potential. A detailed discussion of the electrical double layer theory has been given by Kruyt (1952) and by Dukhin et al. (1974).

During the past decade, extensive work has been carried out to understand the mechanisms of action of polymeric retention aids

used in paper manufacture (Edwards 1985). Fillers and fines suspended in water carry an electric charge. In most cases, this charge is negative and since particles of like charge are repelled, these fillers and fines tend to be well dispersed and are small enough to pass through the wire. To retain these fillers and fines in the sheet, two things have to be done, i.e. first reduce the repellent forces between particles (coagulation), then form a "bridge" between the neutralized particles to produce discrete agglomerates (flocculation) that are large enough to be entrapped in the formed sheet. Electrokinetic techniques are being applied to papermaking system to assess the charge balance of the furnish.

The magnitude of the charge has a significant effect on the efficiency of chemical additives on sheet forming parameters such as retention, drainage and response to vacuum (Penniman 1974, Penniman 1975). The advantages of running the wet end at a near zero zeta potential have been extensively demonstrated under laboratory and mill conditions (Stradzins 1977, Lindstrom et al. 1974). Other improvements of running the papermaking system at zero potential have been reported, i.e. increased wire life, improved pitch control, reduction in biocide use and reductions in sheet breakage at the wet end (Frankle et al. 1973). However, in commercial practice, these findings have not always been confirmed and it appears that zeta potential is not the simple control parameter that was first envisaged (Stratton et al. 1981). Zeta potential should not be used as the sole charge measurement (Stratton et al. 1981, Gill 1988) and other parameters, for example surface charge neutralization, should be used along (Springer et al. 1981).

3.5.2 Instrumentation

Several methods for the measurement of the electrokinetic potential are available. Details of these have been reviewed by Sennet et al. (1965) and Williams (1975). The limitations of each method were highlighted by Stratton et al. (1981), Gill (1988), and Penniman (1988). Most of the available instruments are for laboratory use and only two instruments have been developed for on-line conditions, i.e. the Streaming Current Detector (decribed in details by Gerdes 1966 - figure 37) and the Streaming Potential Meter (Nazir 1994).

At the start of this investigation, the latter instrument was not available and it was decided to experiment with one of the commercially available Streaming Current Detectors. The detector is an off-line instrument where a sample of the stream to be measured has to be diverted to the detector cell. However, the process lends itself to automation and on-line operation with continuous measurement of the charge of the suspension. There is still a good deal of uncertainty on the nature of the signal generated by the piston type streaming current detector. The instrument gives an indication of the surface charge and not the true zeta potential. This research was not intended to investigate the limitations of the charge analyzer or true zeta potential measurements, but rather to find an acceptable method for measuring a "variable" in the papermaking process which will correlate with micro-flocculation phenomena and surface charge requirements.The SCD is used extensively as a control instrument in water treatment. Proper control of the clarification process can result in dramatic improvements in flocculation and sludge settling stability and can bring about savings of chemicals.

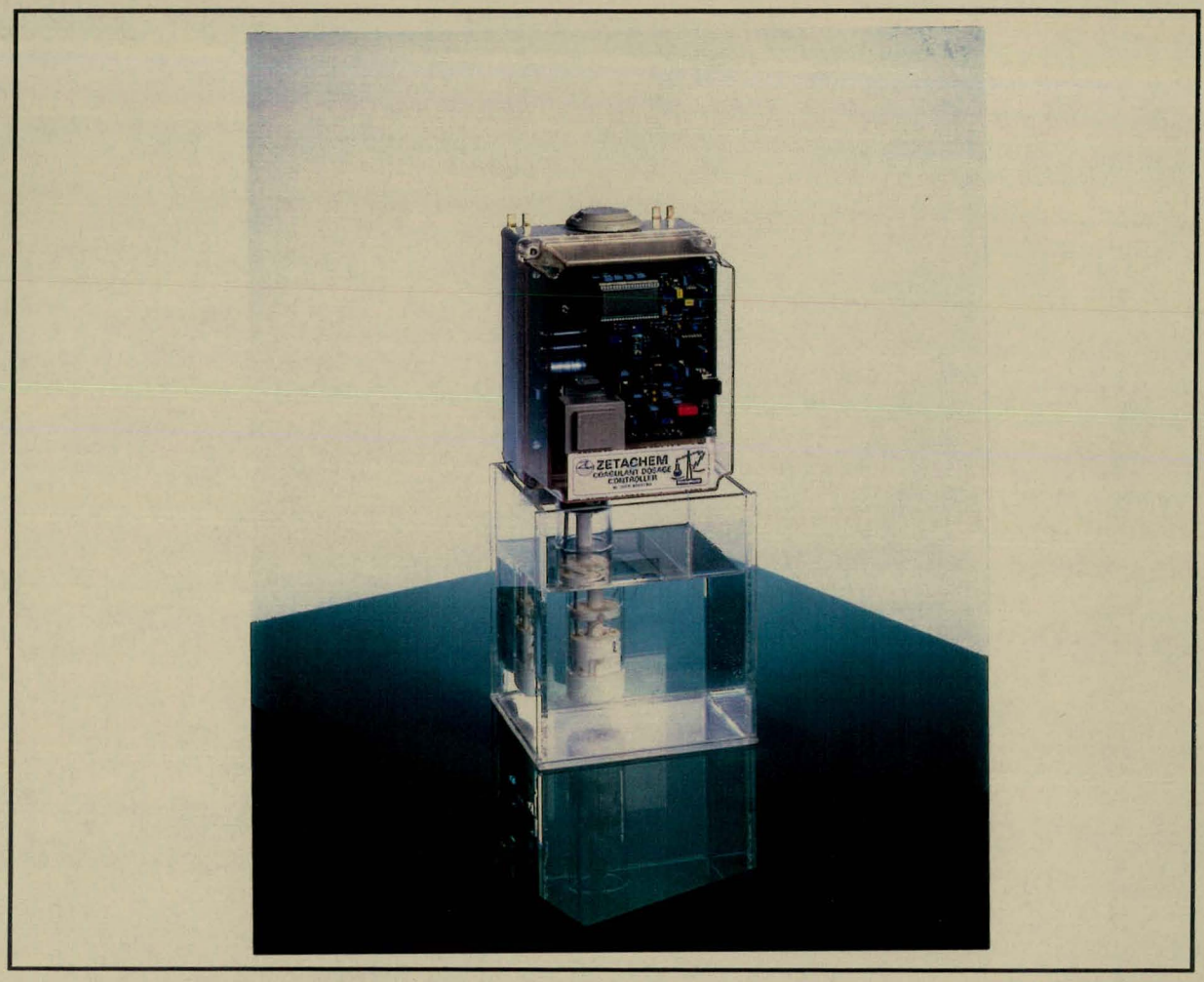


Figure 37 : STREAMING CURRENT DETECTOR

There are certain limitations, as well as variables, influencing the reading from the streaming current detector (Gerdes 1966, Bourbaugh et al. 1967) which have to be considered before positioning the instrument into a control loop. The sensor is calibrated using standardized cationic and anionic solutions. Arbitrary positive and negative values are preset on the instrument. This calibration, unless done with the same standard solution, will be variable. However, this is not to say that such measurements, although not correlating directly to zeta potential, cannot be used to respond to other parameters. The SCD or surface charge analyzer is an instrument ideally suited to determine the point of charge neutralization or isoelectric point. Absolute (non-zero) magnitudes of the zeta potential based on the measurements however, must be regarded as only approximation of undetermined validity.

Temperature changes cause a shift in the readings due to its influence on pH, electric conductivity, dielectric constant and dimensions of the plastic parts of the measuring cell. The temperature of the pulp streams at the wet end of the paper machine does not vary significantly once production has stabilized. Only start-up measurements will be influenced by temperature. The influence of temperature was found to be very small and for the proposed control strategy, it was assumed that temperature will be of no consequence during streaming current detector measurements.

pH variations have a pronounced effect on the instrument reading at low conductivity (Figure 38). Stock of short fiber with a consistency of 1% was made up from unrefined pulp and distilled water. The filtrate was recovered through a 48μm mesh screen and the pH of the filtrate was adjusted by addition of

sulphuric acid. Conductivity of the filtrate was altered with potassium chloride. Acids shift the reading towards the positive side and bases towards the negative. An increase in the pH of the suspension favours the dissociation of acidic groups and the protonization of the cellulose and thereby increases the surface charge (Lindstrom et al. 1974). The surface charge density of cellulosic fibres and fines is also known to increase with an increase in pH (Gill 1989).

The instrument reading varied with a change in conductivity (figure 38). Several phenomena occur simultaneously. A zeta potential decrease may occur without a reduction in the surface charge density as a result of increased concentration of counterions near the surface. Increased ion content in the solution steepens the slope of the potential curve at the boundary of the particle and this reduces the zeta potential without affecting the charge density. The presence of divalent or trivalent metal salts further enhances a reduction in negative reading, and if adsorbed on the surface will reduce the charge density or reverse the sign of charges. Also, a greater portion of the generated streaming current will be lost to the measuring device at higher conductivity as it flows through the parallel conductance of the annulus. This loss of measuring efficiency is of no consequence when determining the ultimate conductivity of the sample solution at which measurements may be obtained. The limitation rather seems to be linked to the frequency of the current signal, which results from pressure effects on the electrodes (Gerdes 1966) and which may become significant at higher conductivity and also offset the instrument zero.

The streaming current detector reading will need to be corrected for the variation in pH and conductivity over the range found at

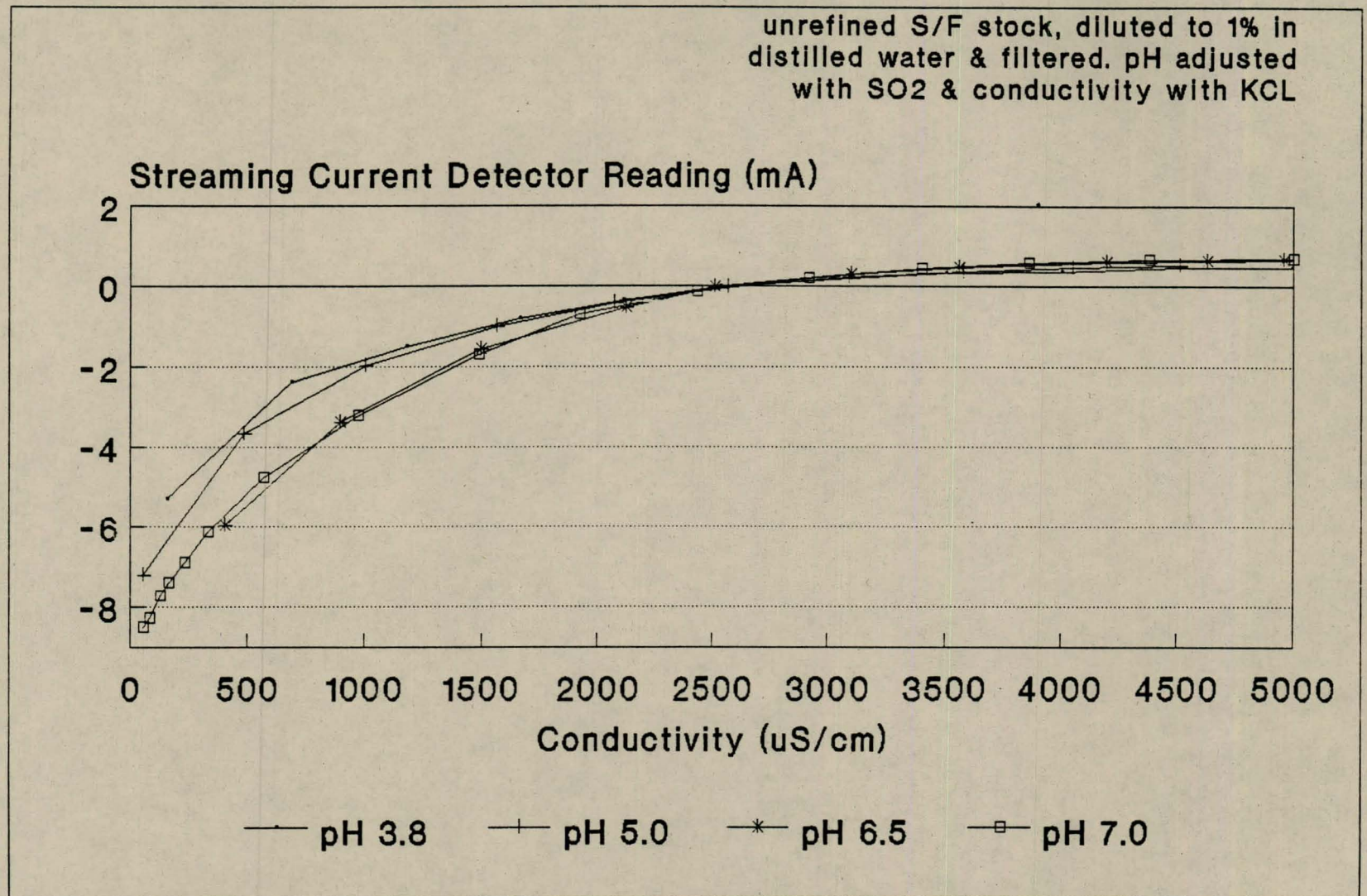


Figure 38 : STREAMING CURRENT DETECTOR READING versus pH AND CONDUCTIVITY

the papermachine, i.e. pH = 5,5 ± 0,5 and conductivity = 0 to 4000 µS/cm. More work is required with the instrument installed on-line to establish the exact sensitivity of the instrument.

Another drawback of this instrument is related to the geometry of the measuring cell within the annular gap between the bore and the piston. Fibrous material and coarser particles will interfere with the operation and the samples must be filtrated. An in-line filtering device was thus designed (figures 39) which allows to recover the filtrate from the pulp stock or machine white water. The filtrate passed through a stock pad which is formed by the filter mesh and flowed to the streaming current detector cell. The thickness of the fibre pad is limited by the flow velocity of the stream in the core of the filter. Sequential backwash of the filter to avoid clogging and influence of the charge by the retained fiber mat was carried out with air and/or water. The filtrate was clean enough for proper operation of the detector. However filtering the pulp sample before charge measurement questions the relevance of surface charge measurement of fines (Britt 1974). This includes comparison both of fines with whole fibre and different sizes of fines with each other. It seems that direct comparison of the zeta potential of long fibres and fines will be difficult if not impossible to perform. Stradzins (1972) made the following cogent points in arguing for a zeta potential for all pulp components:

a) the fines originate from the surface of individual fibres. It should therefore have a similar surface potential to that of the fibres;

b) in addition, dissolved hemicelluloses and other polysaccharides adsorb on the surfaces of the fibres and fines. This also tends to produce an uniform surface potential throughout the pulp;

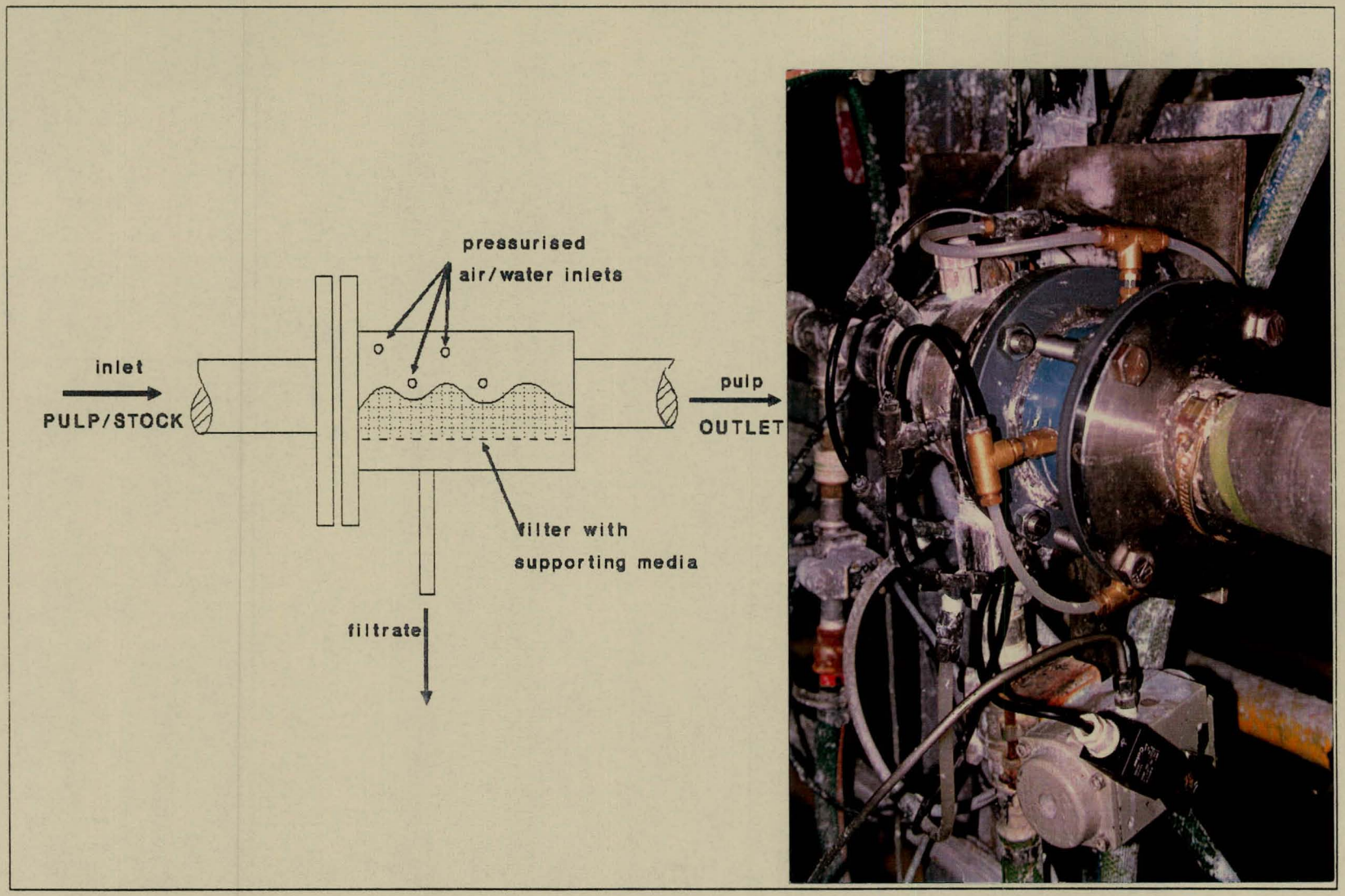


Figure 39 : STREAMING CURRENT DETECTOR IN-LINE FILTER

c) because zeta potential is primarily determined by the surface potential and is little influenced by the composition of the underlying material, it therefore would be expected to be the same for fibres and fines.

However, in apparent contradiction to these arguments are the recent studies of Smith (1977) on the zeta potential distribution in newsprint furnishes using a microelectrophoresis technique. Britt (1979) suggested that Smith's results are caused by a distribution of particle sizes rather than surface potentials. This is confirmed by Gill (1989) which did not find any relationship between different levels of refining, i.e. increased fines content, and the polyelectrolyte titration charge of the solution.

The possible identity of different zeta potentials for fibres and fines has not yet been satisfactorily established in the literature, but some evidence and logical arguments suggest an affirmative answer. The findings of Smith (1977) suggest that the measurement of only a few particles may be insufficient to accurately characterize a pulp. Whether other properties such as retention and drainage only depend on an average value or are characterized by a zeta potential distribution is not known. This is still one of the drawbacks of this instrument where the sample of pulp has to be filtrated in order to measure the electrokinetic property of the stream.

3.5.3 On-line Measurement

The sensor was installed on a paper machine for a trial period to evaluate the relationship between the streaming current detector reading and retention (figure 40). The readings were not corrected for pH and conductivity variations. The two signals were following the same pattern and it seemed that either one could be used as the measuring signal.The silo charge was always lower than the headbox charge and could be due to two reasons, i.e.:

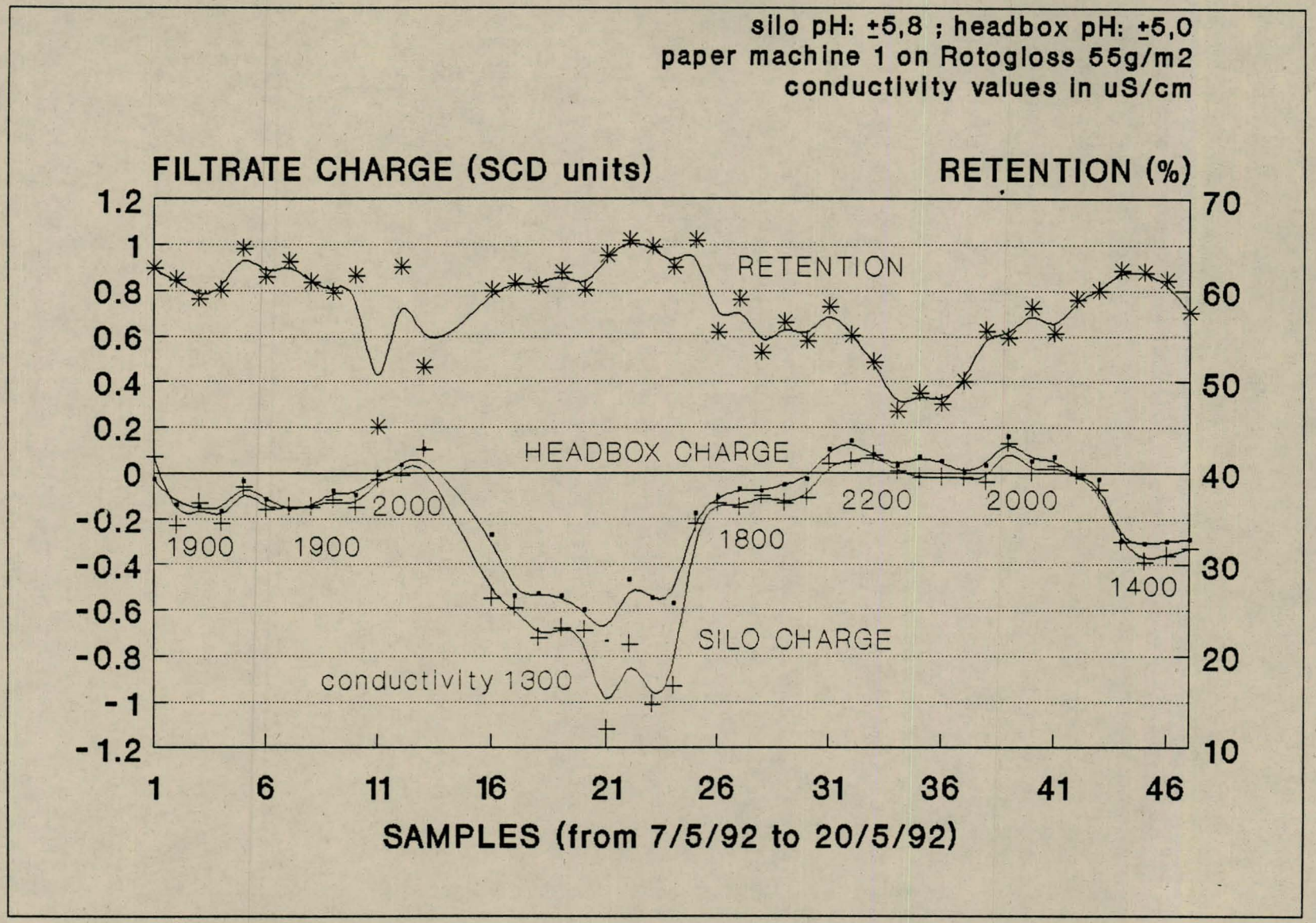


Figure 40 : STREAMING CURRENT DETECTOR HEADBOX & SILO CHARGE versus RETENTION

a) the silo pH was generally higher than the headbox pH during the evaluation period and a correction factor may be required;
b) the clay slurry may have a charge slightly more negative than the fibres and as the ratio of clay to fibre in the silo white water is higher than in the headbox, this could explain the slight difference.

The relationship between retention and charge is difficult to analyse at this point in time as the results were not corrected for the white water conductivity differences between each measurements. From figure 38, the charge reading varies by ± 1 unit from 1300 μS/cm to 2000μS/cm. This will explain the higher retention obtained with the lower charge reading (-0,8) and lower conductivity (1300μS/cm) compared to the same retention at a higher conductivity (1900μS/cm) and higher charge (-0,1 compared to -0,8). However it is apparent that retention decreased sharply at or above the isoelectric point.

A multi-variable analysis is required to establish the relationship between charge and retention taking into account the white water conductivity and pH. Floc formation was another variable which was not quantified during the trial period. More work is needed before installing the streaming current detector on the paper machine. However, the signal generated by the instrument can be useful for controlling the addition rate of the retention aids to attain an uniform retention.

3.5.4 Process Control Strategy

Charge control must be linked with retention and sheet formation control strategies. Charge control should consist of three control loops, i.e.:
a) control and neutralization of interfering substances in the

pulp stream;
b) control and neutralization of interfering substances in the stock preparation area with charge site preparation on the fibres for sizing, cationic starch retention, etc;
c) retention and sheet formation control loops for the addition of retention aids added in the thin stock loop for optimum first pass retention.

3.5.4.1 Mechanical pulp preparation

In the groundwood mill for example, pitch and interfering substances are controlled by using a synthetic polymer added in the grinder shower water tank and in the grinders discharge pipe. The control loop (figure 41) will measure the stock charge after leaving the discharge pipe and adjust the addition of polymer (coagulant) added in the shower tank and the discharge pipe with priority to the grinder shower water tank. Conductivity should also be measured to correct the charge reading, when using the streaming current detector (pH does not vary significantly to warrant correction). The minimum addition rate to the shower water tank ensures that no deposition of pitch and clogging of the stone will occur, which can result in subsequent stone rupture due to temperature stress. A similar strategy can be applied to the thermomechanical plant.

3.5.4.2 Stock preparation

After blending of the various pulp streams, charge must be measured to neutralize the presence of interfering substances from the broke stream, chemical pulp stream and recycled white water used for pulp dilution. This will introduce bridging sites on the fibres for the retention of additives. A coagulant

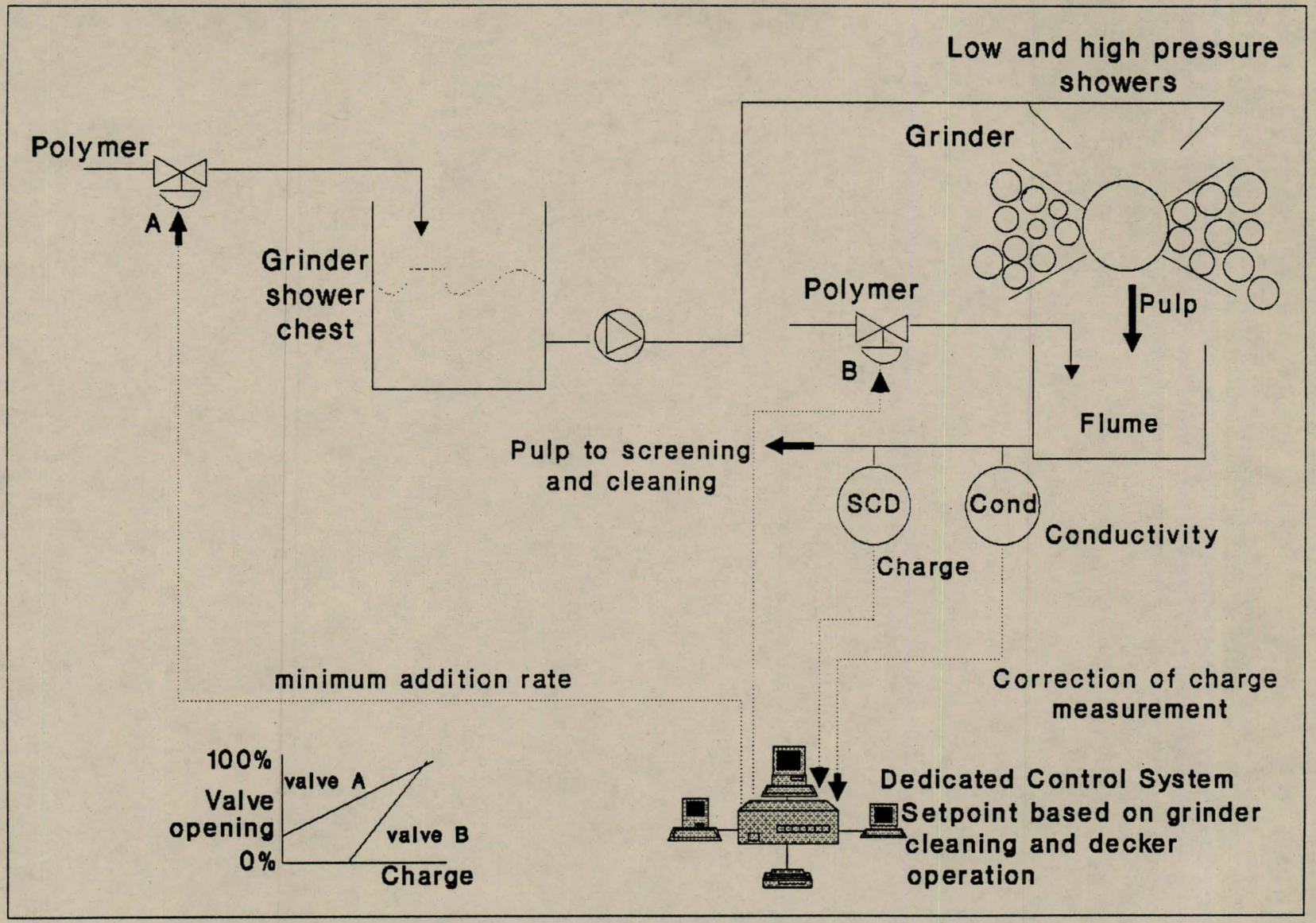


Figure 41 : GROUNDWOOD PULP PREPARATION
COAGULANT ADDITION CONTROL

should be added to the blend chest. If alum is used for sizing purposes, it would be more meaningful to add it further down the line (before the blend chest pump for example) to ensure that the aluminium ions are available for sizing purposes and rather use the synthetic coagulant for trash neutralization (figure 42).

3.5.4.3 Retention control

As discussed under section 3.4.5, consistency measurements are not enough to control the entire retention mechanism. The electrokinetic properties of the furnish should be known in order to establish if retention aid dosage should be increased or decreased during periods of fluctuation. The streaming current detector will measure the charge of the silo filtrate (figure 43). From the ash retention and silo charge, the addition rate of the coagulant will be controlled before the 1st fan pump to pretreat the stock before addition of the filler. Care must be taken not to overcharge the fibres at this point. The stock charge should still be negative after coagulant addition to allow the flocculant to act and bridge the matrix. At this point in time, no instrument is available to measure "floc formation" and the addition rate of the flocculant after the screens will be controlled with the total solids retention results and adjusted proportionally with the coagulant addition rate. With the development of new sensors for floc formation and drainage, this control loop will be modified and the addition rates of the flocculant and the coagulant will become independent as the action of these chemicals are completely different.

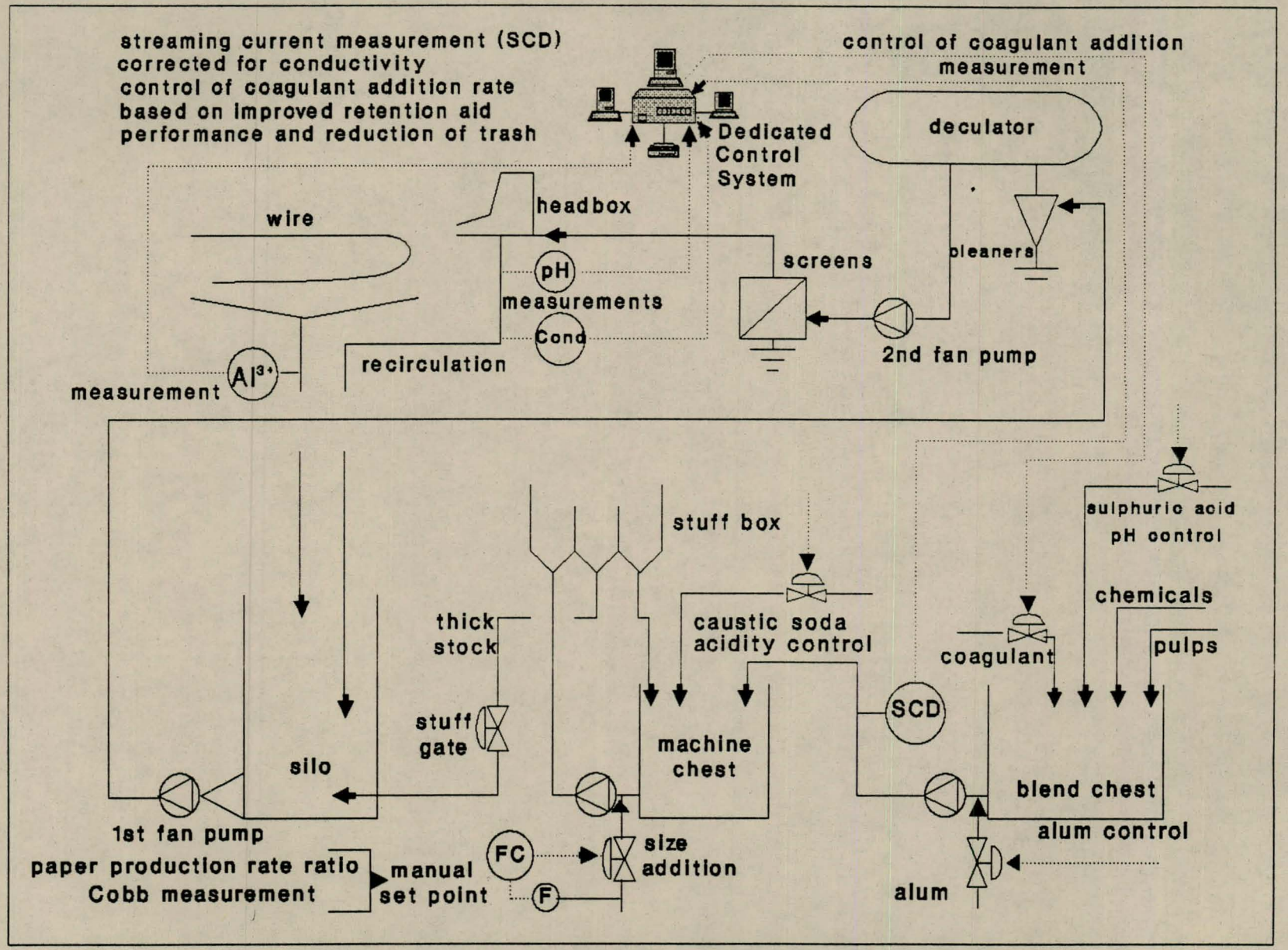


Figure 42 : APPROACH FLOW COAGULANT CONTROL

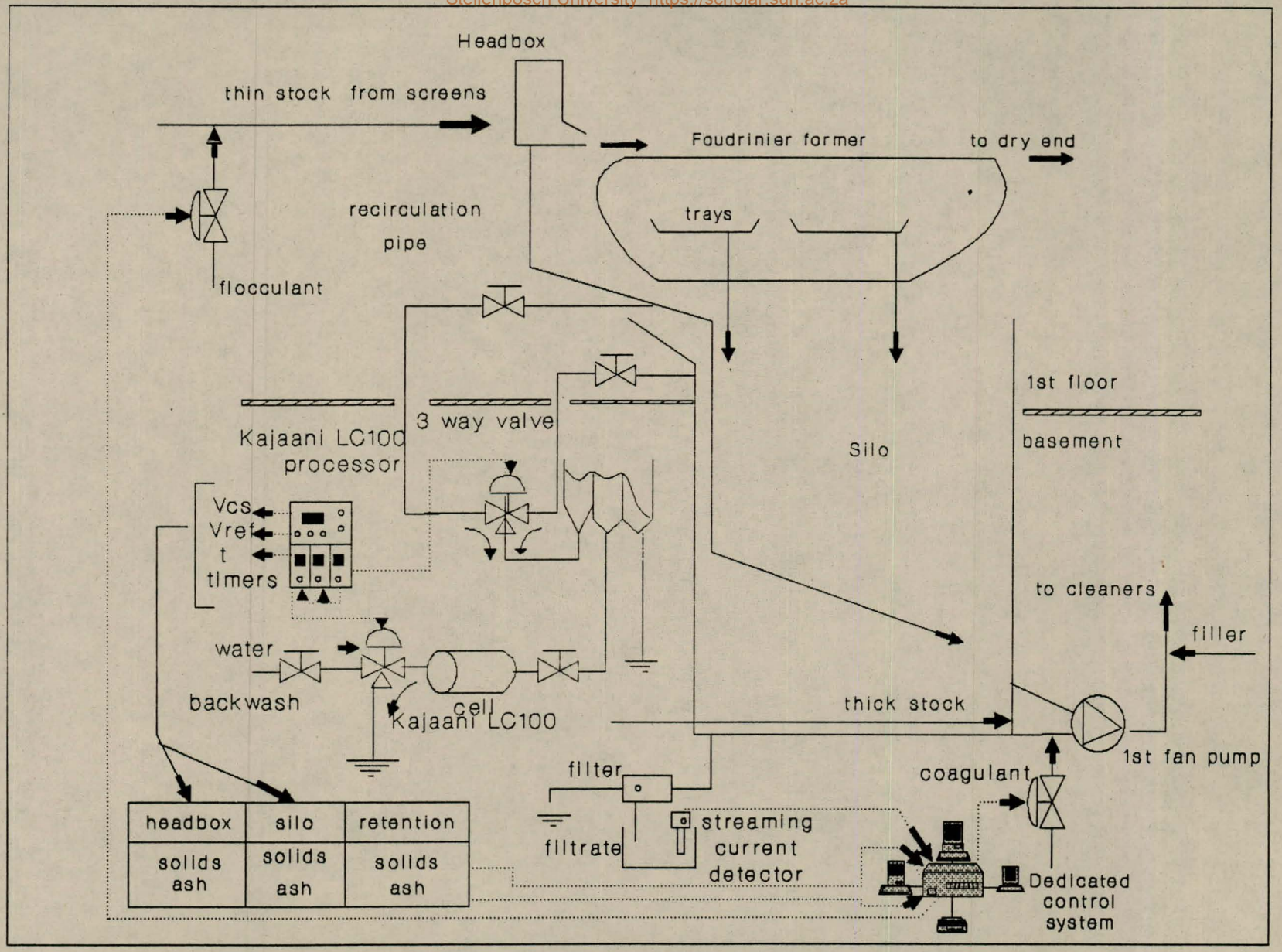


Figure 43 : RETENTION CONTROL

3.6 BRIGHTNESS and SHADE CONTROL

3.6.1 MECHANICAL PULPING

The increased and diverse use of mechanical pulps have brought with it higher quality requirements. Pulp brightness together with strength properties, is one of the fundamental quality factors determining the potential use of this type of pulp.

To meet these higher brightness and brightness stability requirements, controlled chemical consumption and better control over bleaching are needed. Many mills still rely on manual control over dosage of bleaching chemicals with addition rate adjusted according to production rate and results from laboratory analysis. Stable brightness levels are difficult to achieve due to the lag time between sampling and the results of the analysis, and the disregard to variations of other process variables, such as incoming pulp brightness, chemical concentration, pH, and consistency.

3.6.1.1 Sodium hydrosulphite bleaching

Sodium hydrosulphite is used at the Mondi Paper Company Merebank Mill for bleaching of thermomechanical (TMP) and part of the groundwood (GWD) pulp. We will use the example of the TMP plant to illustrate the benefits of converting the control of pulp brightness from manual to automatic.

Samples of TMP pulp were taken every 2 hours at the decker chest on each of the two lines and the amount of sodium hydrosulphite added was manually adjusted dependent on the pulp brightness and the specification for the paper grade

(newsprint with different shades at the time). A statistical analysis of the pulp brightness showed an average brightness of 60,6 ISO with a standard deviation of 1,33 (figure 44) for the manufacture of shade 3 newsprint stock. The paper machine brightness variation, influenced by the stock brightness variability, was 59,7 ISO with standard deviation of 1,05 (figure 45). The minimum brightness for shade 3 newsprint is 58,5 ISO, which means that 60% of the pulp was overbleached to meet the required specification and 5,7% of production was below specification (Figure 46).

The use of a brightnes sensor (Cormec-M from Kajaani) was then evaluated. This sensor measures the pulp brightness on-line using optical principles. Variations in pulp flow rate, stock temperature and consistency can be taken into account for improved measurement. A sensor was purchased and installed in the stock line from the decker chest to the storage chest, with a feedback control loop to control the sodium hydrosulphite addition rate (Figure 47). After calibration of the sensor, an auditing of brightness variation was carried out. A comparison of sensor readings and laboratory analysis (figure 48) shows a good correlation between the two sets of data. Peaks tend to be averaged due to the sensor reading software and the fact that no compensation for stock temperature, consistency and flow rate were allowed for.

The average brightness of the TMP stock after the sensor installation was 60,4 ISO with a standard deviation of 0,70 (figure 49) and newsprint average brightness was 60,4 ISO with a standard deviation of 0,48 (figure 50). The process capability has improved considerably with a lower range of brightness variation (reduced by 47%). All stock is within specification and

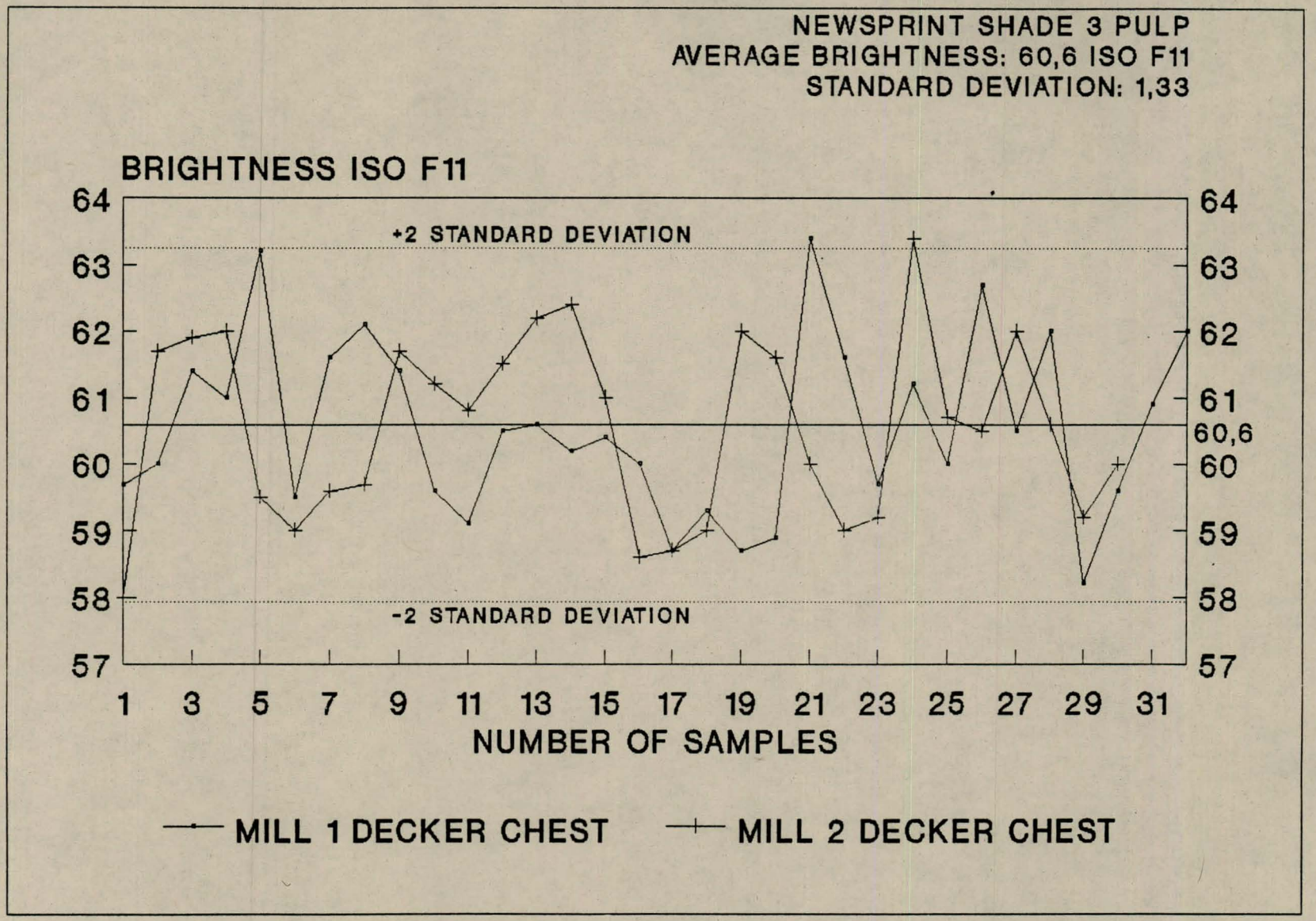


Figure 44: TMP PULP BRIGHTNESS VARIATION MILL 1 & 2 DECKER CHESTS

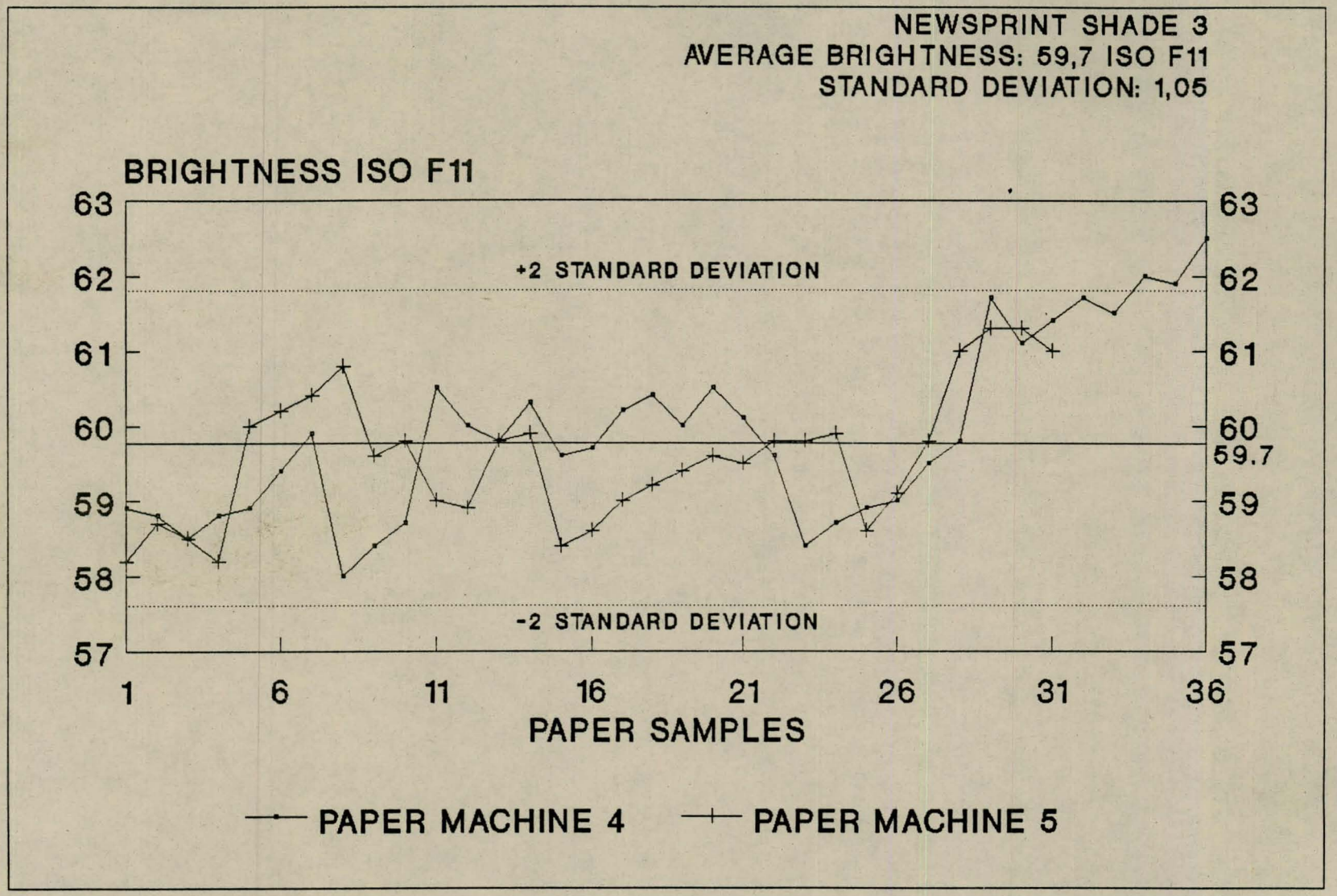


Figure 45 : PAPER BRIGHTNESS VARIATION
NEWSPRINT PAPER MACHINES 4 & 5

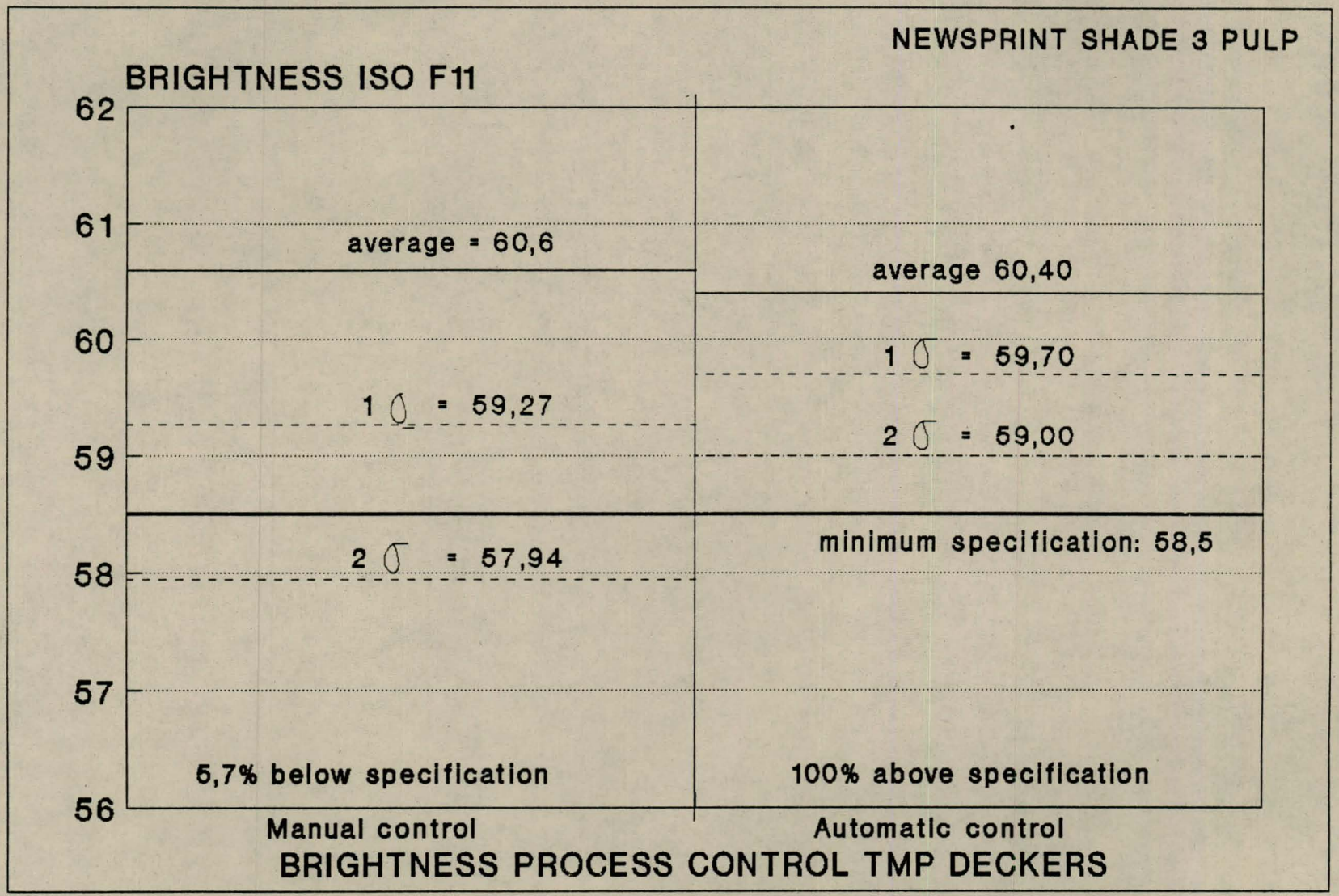


Figure 46: TMP PULP BRIGHTNESS VARIATION
PROCESS CAPABILITY

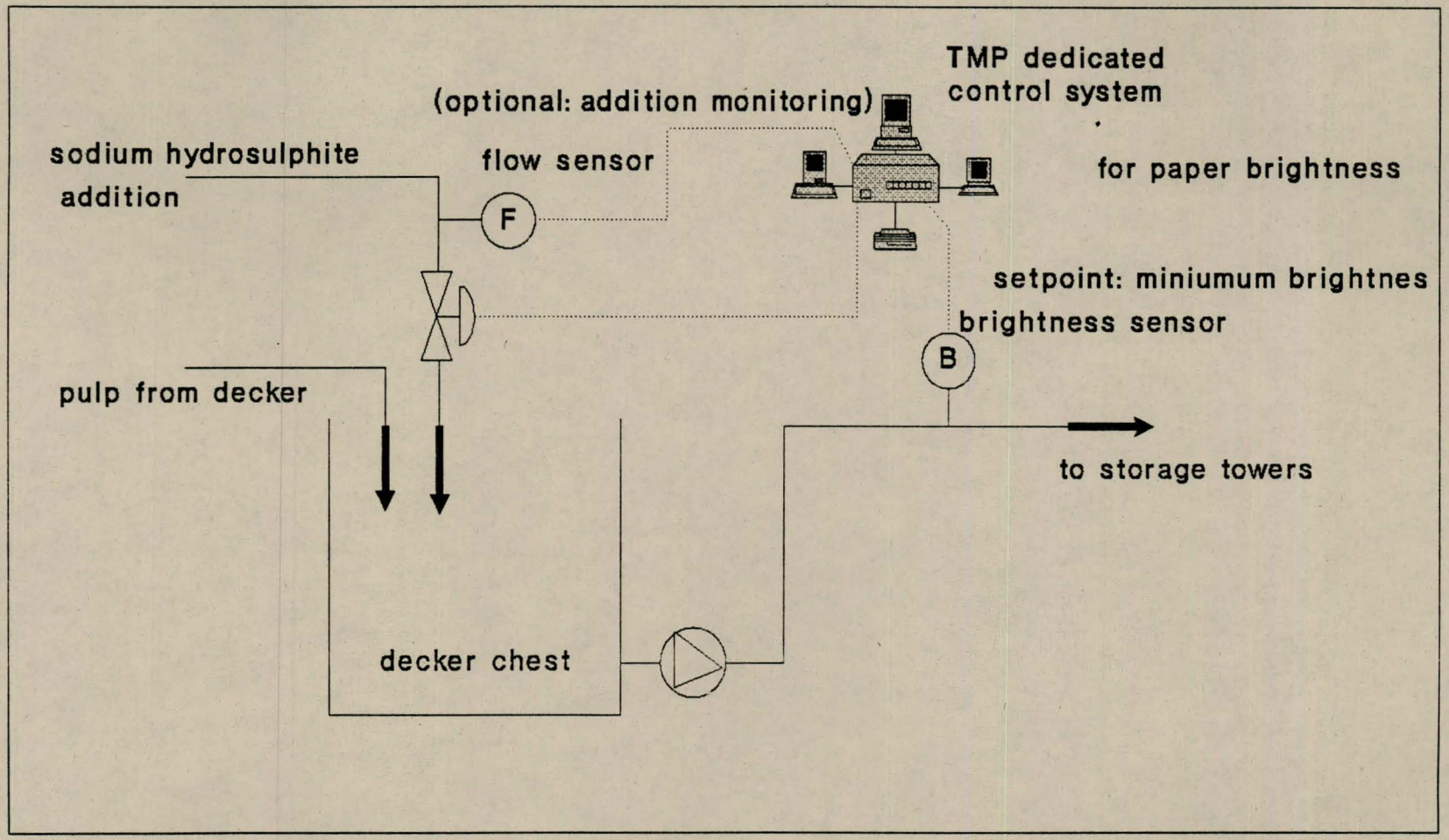


Figure 47 : TMP BRIGHTNESS CONTROL
ON-LINE BRIGHTNESS SENSOR INSTALLATION

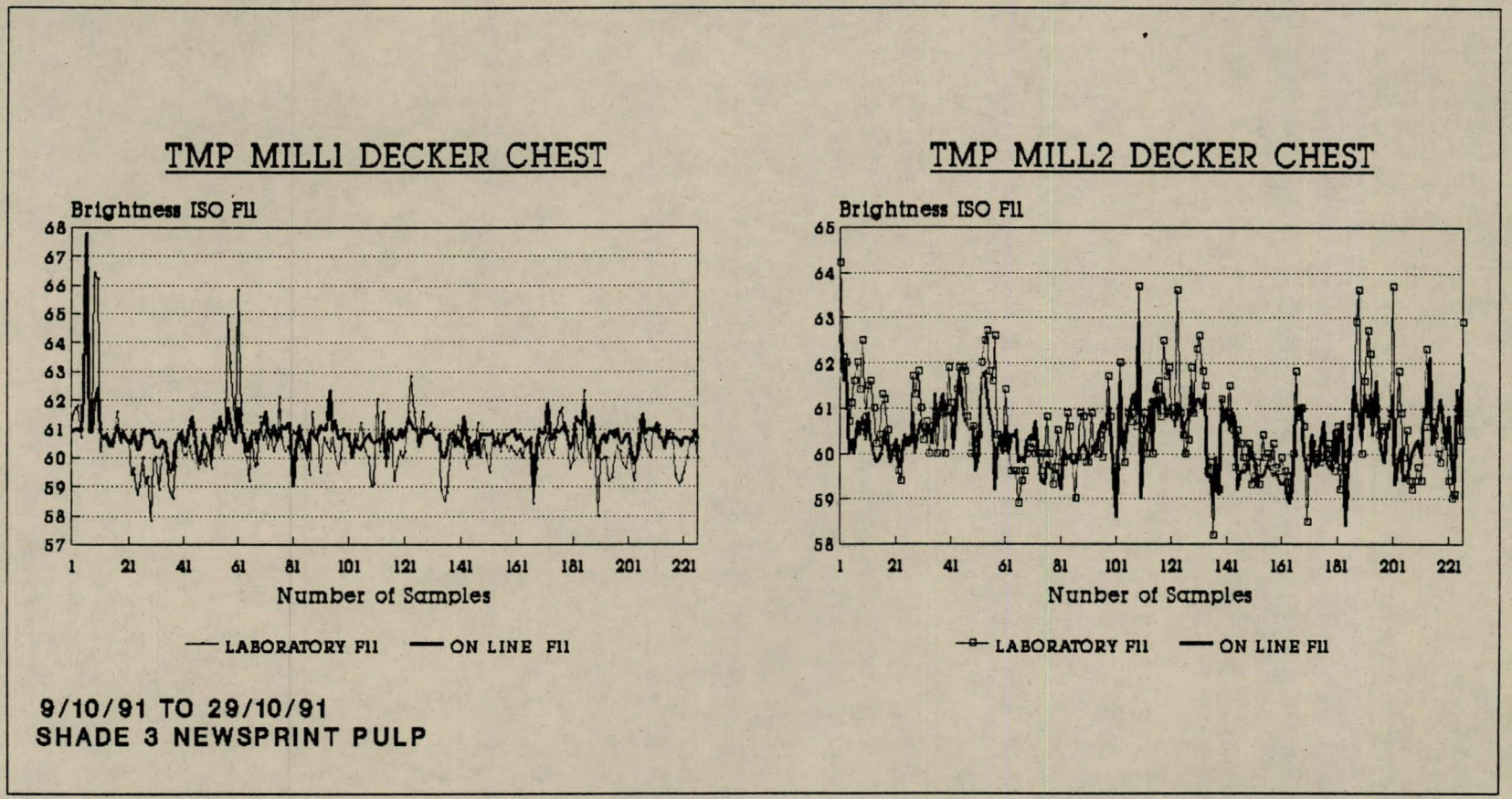


Figure 48 : TMP BRIGHTNESS SENSOR EVALUATION
LABORATORY vs ON-LINE SENSOR MEASUREMENTS

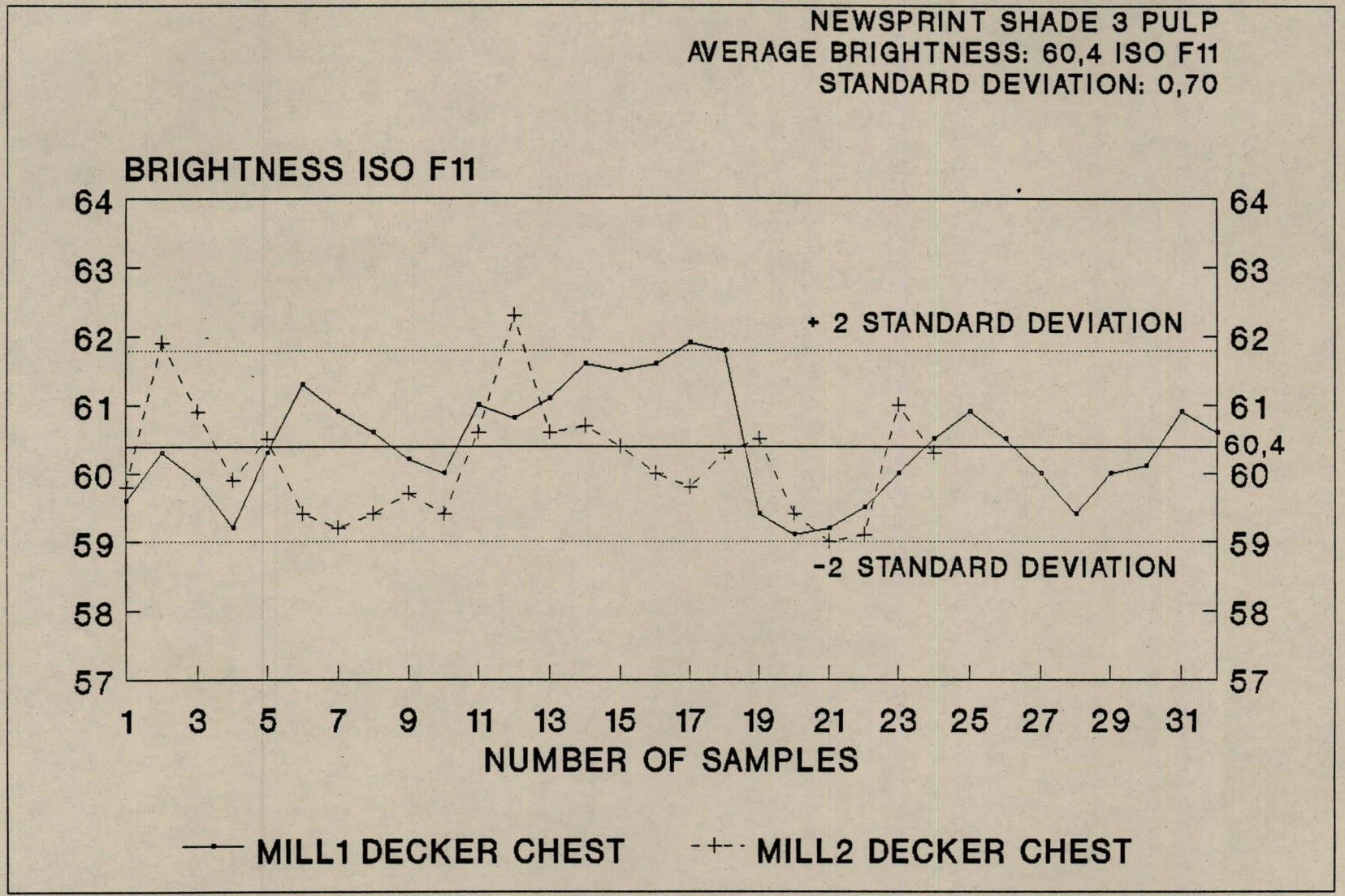


Figure 49: TMP PULP BRIGHTNESS VARIATION
MILL 1 & 2 DECKER CHESTS
AFTER BRIGHTNESS SENSOR INSTALLATION

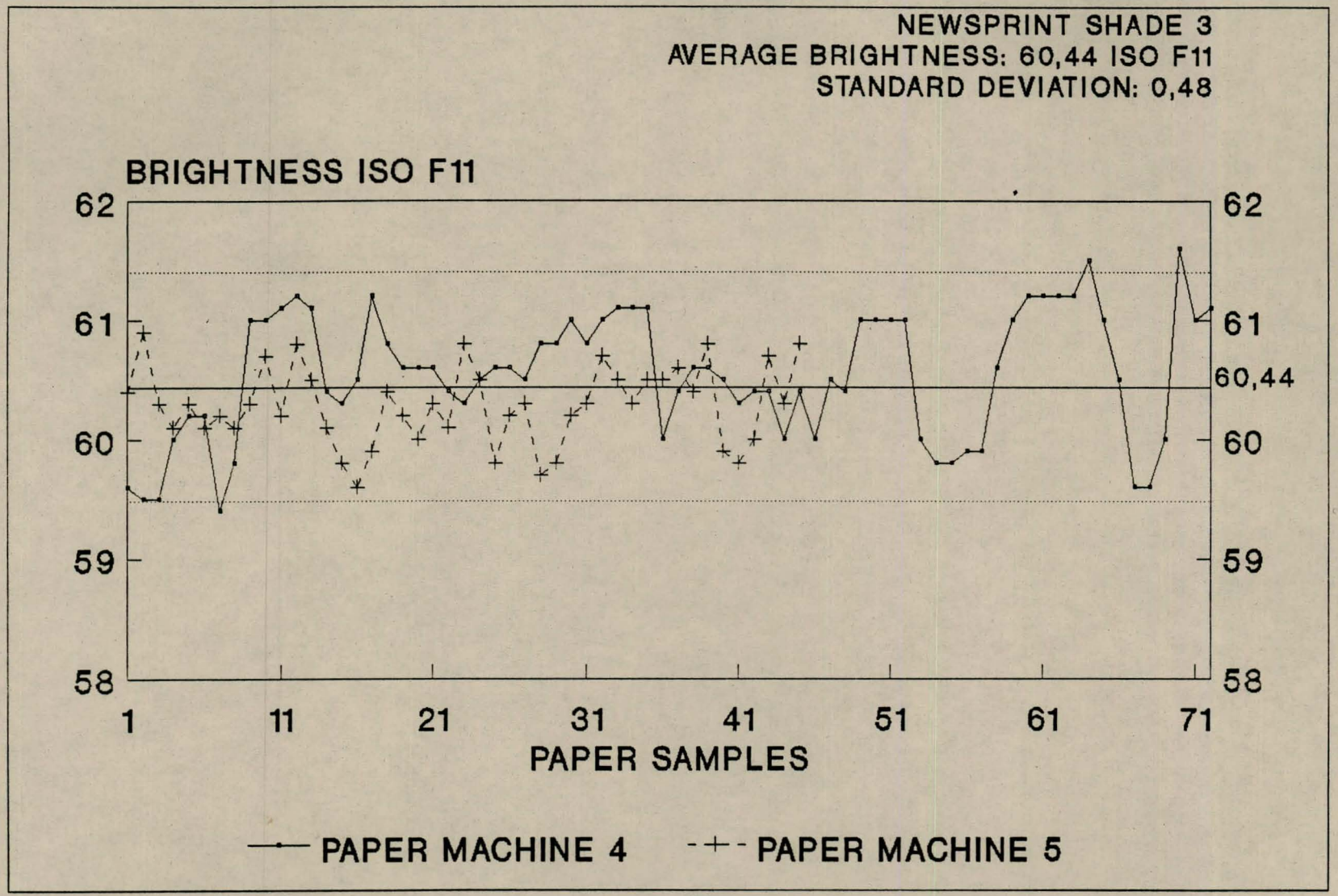


Figure 50 : PAPER BRIGHTNESS VARIATION
NEWSPRINT PAPER MACHINES 4 & 5
AFTER BRIGHTNESS SENSOR INSTALLATION

a safety margin is kept. Also, brightness losses in the pulp storage towers and paper machine blending chests decreased from 0,8 to 0,2 ISO. Improved process capability resulted in the reduction of TMP sodium hydrosulphite consumption by ±29% during the period audited (figure 51). This could have been improved by reducing the safety margin and lowering the pulp brightness average. Furthermore, brightness related broke figures recorded on the paper machine were reduced considerably.

Increased pulp brightness control with reduced variability and reduced sodium hydosulphite usage resulted in the project having a payback of 3 months. The installation of the control loop provided early warning signs which eliminated occurence of out-of-specification pulp quality.

3.6.1.2. Hydrogen peroxide bleaching

For paper grades requiring high mechanical pulp brightnesses (above 70 ISO), peroxide bleaching is necessary. The chemicals control requirements for peroxide bleaching will be described for the proposed upgrading and control of the Merebank bleach plant (Figure 52 -Durgueil et al. 1992).

The first chemical to be added is a chelating agent to complex the metal ions present in the stock (mainly ferrous and ferric ions) originating either from the wood or from process metal corrosion. As no on-line instrumentation is available to measure the amount of metal ions, the addition rate is proportionally controlled with the stock flow rate and from the results of the laboratory analysis of the stock average ion content. The second chemical to be added is caustic as peroxide bleaching

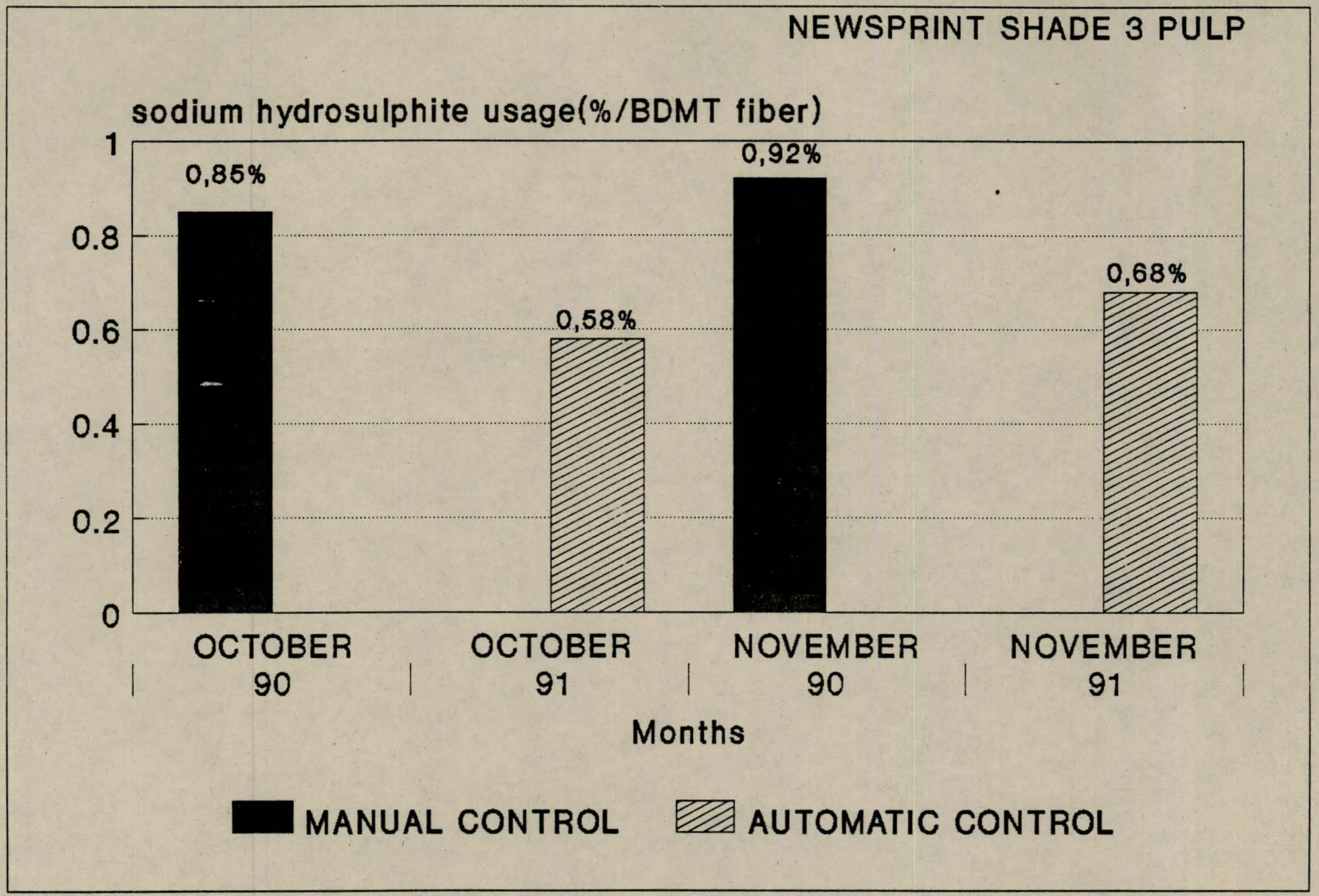


Figure 51: TMP BRIGHTNESS CONTROL
SODIUM HYDROSULPHITE CONSUMPTION

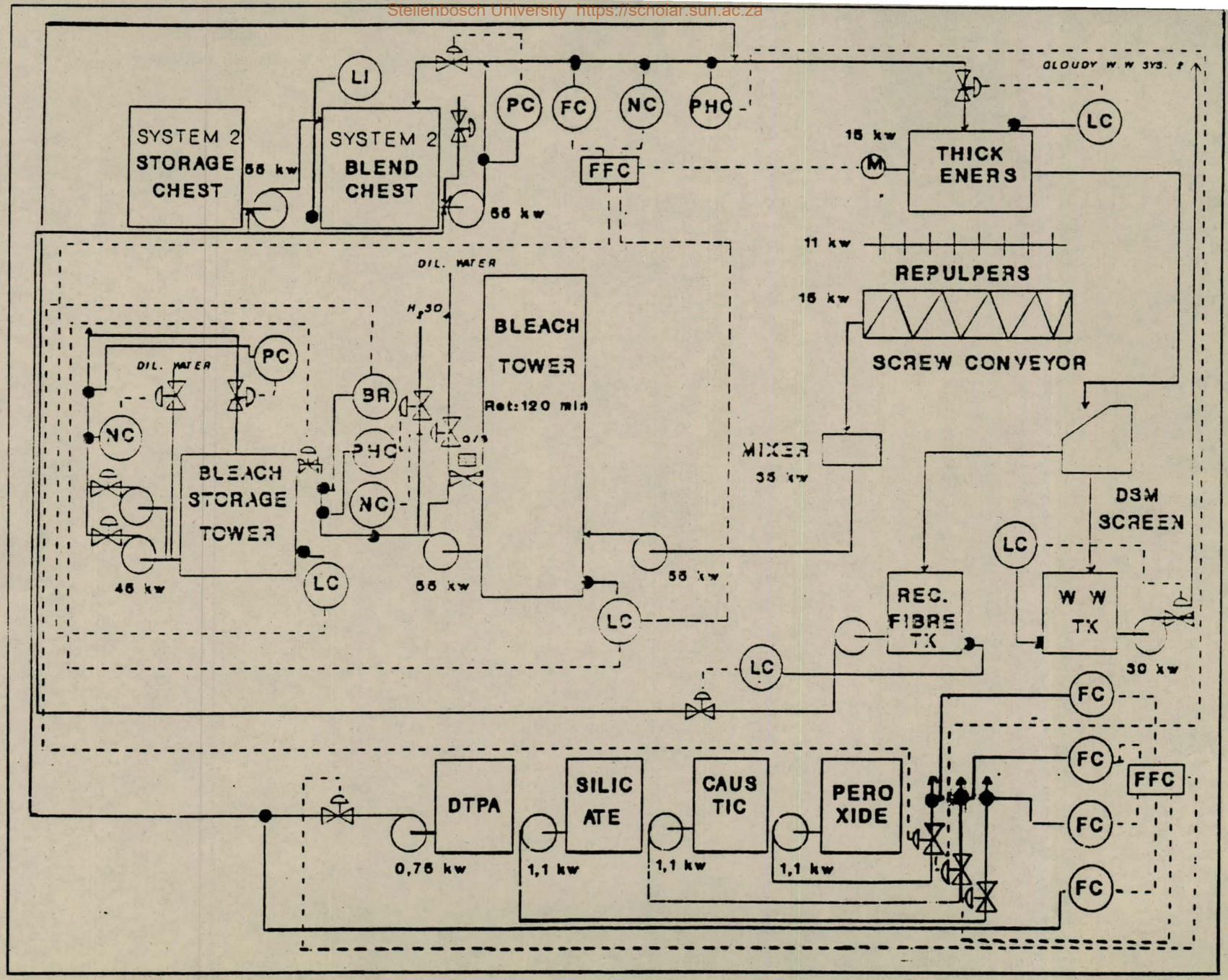


Figure 52 : PROCESS CONTROL DIAGRAM FOR BLEACH PLANT

requires an alkaline medium. This is generally done in a feed forward loop. pH of the stock to the bleach plant is measured and an excess amount of caustic is added to the thickened pulp with the bleach liquor. One of the problems experienced with such a control is the variable acidity of the stock from the pulp plant. The control can be improved by either measuring the pH of the thickened stock (pH probes are not very accurate when measuring stock at ± 15% consistency) with the signal feeding back to control the amount of caustic added in the bleach plant, or if the pulp plant can handle higher white water pH for shower and dilution water, by controlling the diluted stock pH before the bleach plant.

The third chemical added is sodium silicate which tends to be replaced more and more by organic complexing agents due to interactions and negative influences with retention aids (Gunder et al. 1975, Ali et al. 1990). Sodium silicate is added in the bleach liquor in a control loop in proportion to the stock flow. Peroxide is then added and controlled by a brightness sensor, installed after the bleach tower in a feedback loop. The gain and lag time must be adjusted carefully to take into account the retention time in the bleach tower. The last chemical to be added is sulphuric acid to stop the peroxide bleaching reaction after the bleach tower. This is controlled by a feedback loop using a pH probe installed in the diluted stock after the bleach tower.

For higher brightness or to reduce bleaching variable costs, a second bleaching stage can be added using sodium hydrosulphite. A second brightness sensor will be required after the bleach storage tower which will control, on a feedback control loop, the addition rate of sodium hydrosulphite to the

bleach storage tower.

The statistical analysis of the bleached groundwood pulp brightness (Durgueil 1990) showed an average 72,9 ISO brightness and a standard deviation (2σ) of 2,8 units.

The process capability can be reduced significantly with the installation of brightness sensors as shown by the TMP plant results.

3.6.2 PAPER SHADE AND BRIGHTNESS CONTROL

Paper shade and brightness are key quality parameters as differences are easily detected by the human eye. Shade and brightness determinations were carried out in the past by the laboratory every time a jumbo reel was produced, i.e. the measurement of this vital quality parameter is done approximately once an hour or once every $\pm$12t of paper produced. Process variability is high as shown in figure 53. Out of range variation in brightness results in high broke production (figure 54). The delay to detect an out-of-control situation and the lag time involved to return to control are contributing factors.

For the last decade, on-line dry end optical sensors (spectrophotometers) are commercially available (Accuray, Measurex sensors) and their technology is well proven worldwide. Various trials carried out at the Merebank mill showed that the process capability could be increased significantly, hence reducing the amount of broke produced, as well as the time required to adjust shade during grade change.

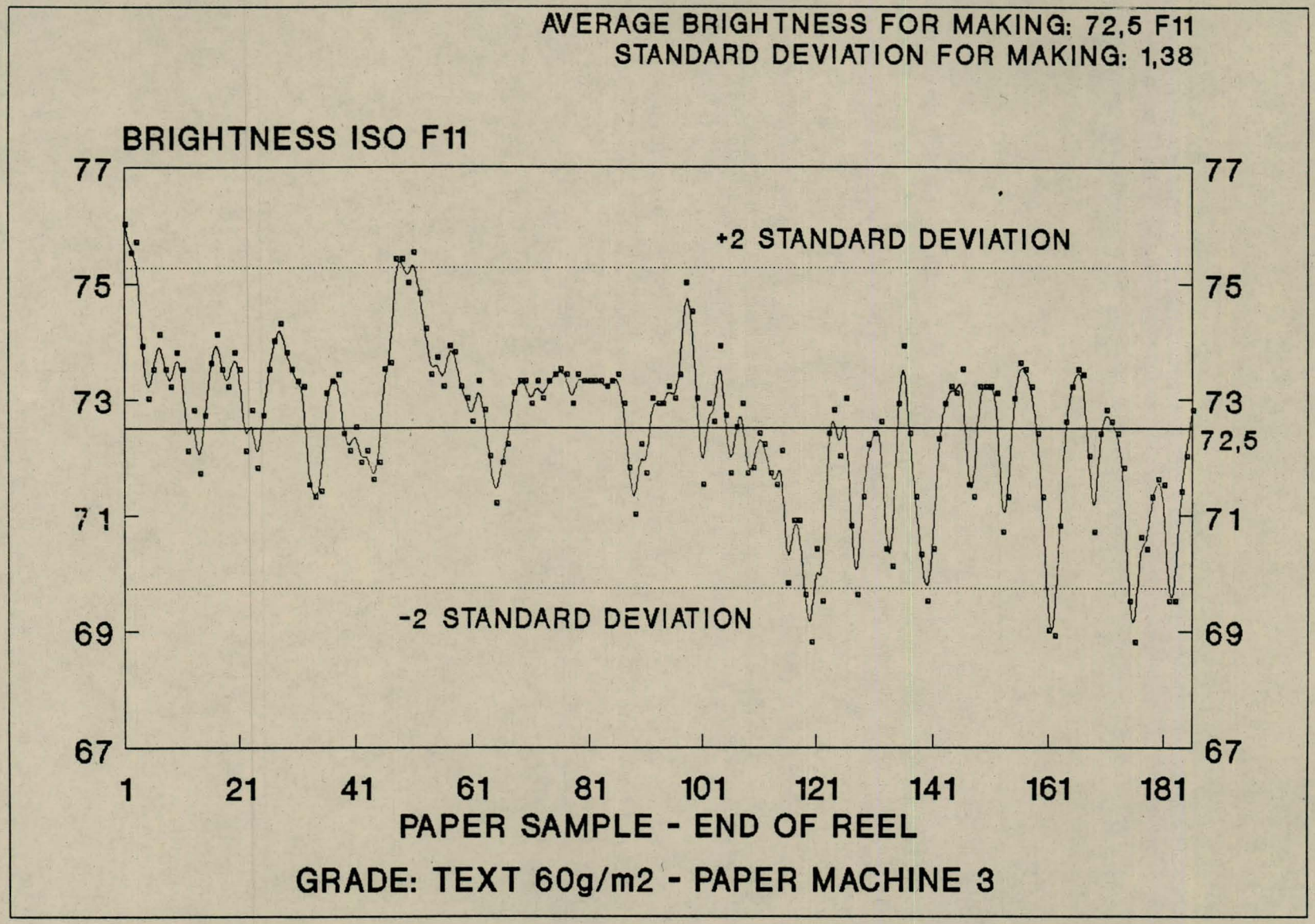


Figure 53 : PAPER MACHINE BRIGHTNESS VARIATION

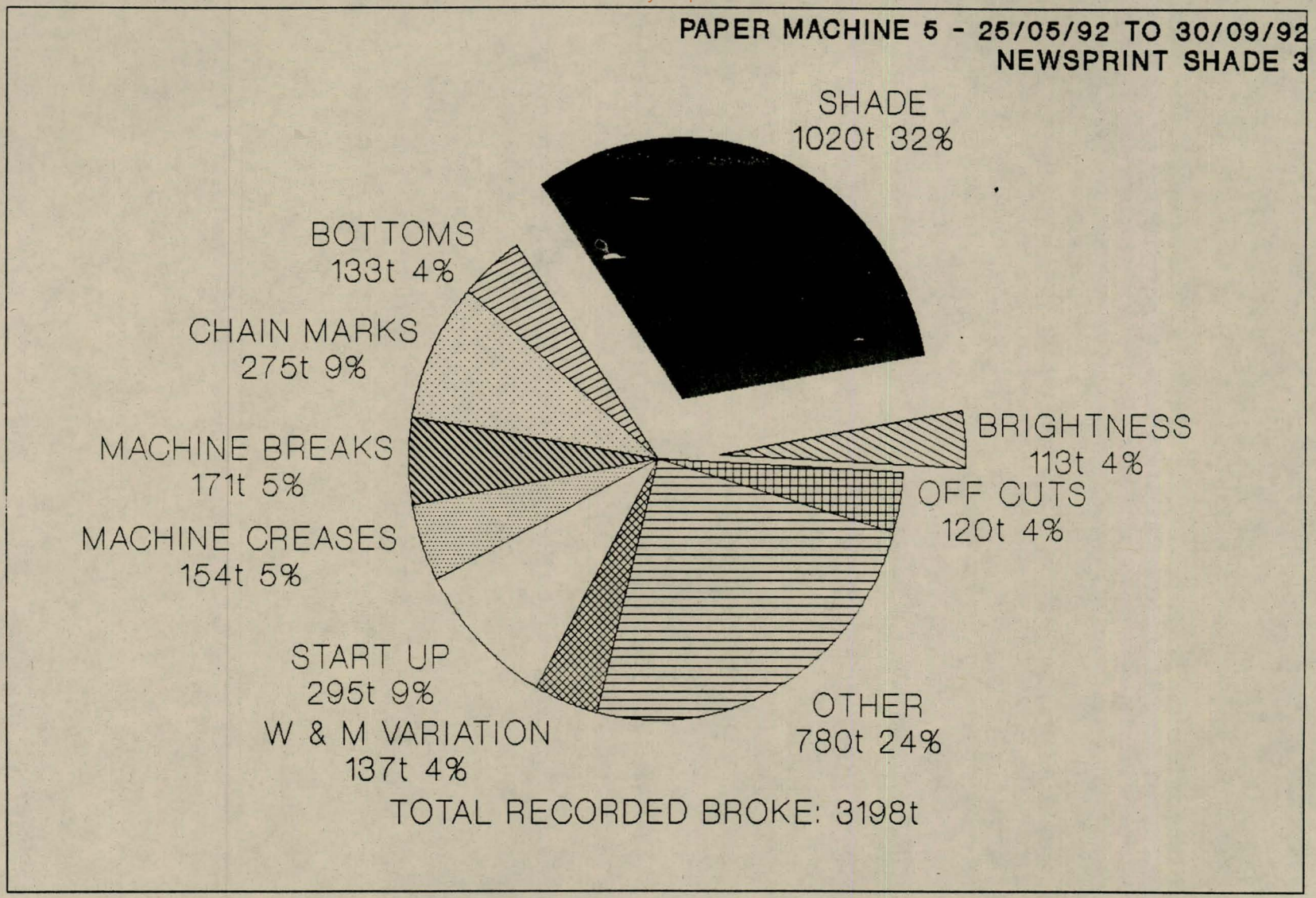


Figure 54 : BROKE LOSSES DUE TO SHADE AND BRIGHTNESS VARIATIONS

A sensor installed at the dry end of the paper machine continuously scans the sheet of paper and controls on a feedback loop (figure 55), using proprietary software, the flowrate of dyes (generally 2 to 3 dyes) added at the wet end of the machine. The flowrate control has been carried out using metering pumps due to the small amount of dyes injected but with the advances in the development of small control valves and flowmeters, it is possible to control the addition rate of each dye with a control valve and flowmeter, thereby reducing the maintenance cost associated with the positive displacement pumps.

The dyes are generally added to the first stage cleaner reject tank to insure proper mixing of the dyes with the lean stock due to the turbulence and agitation in the chest and approach flow piping.

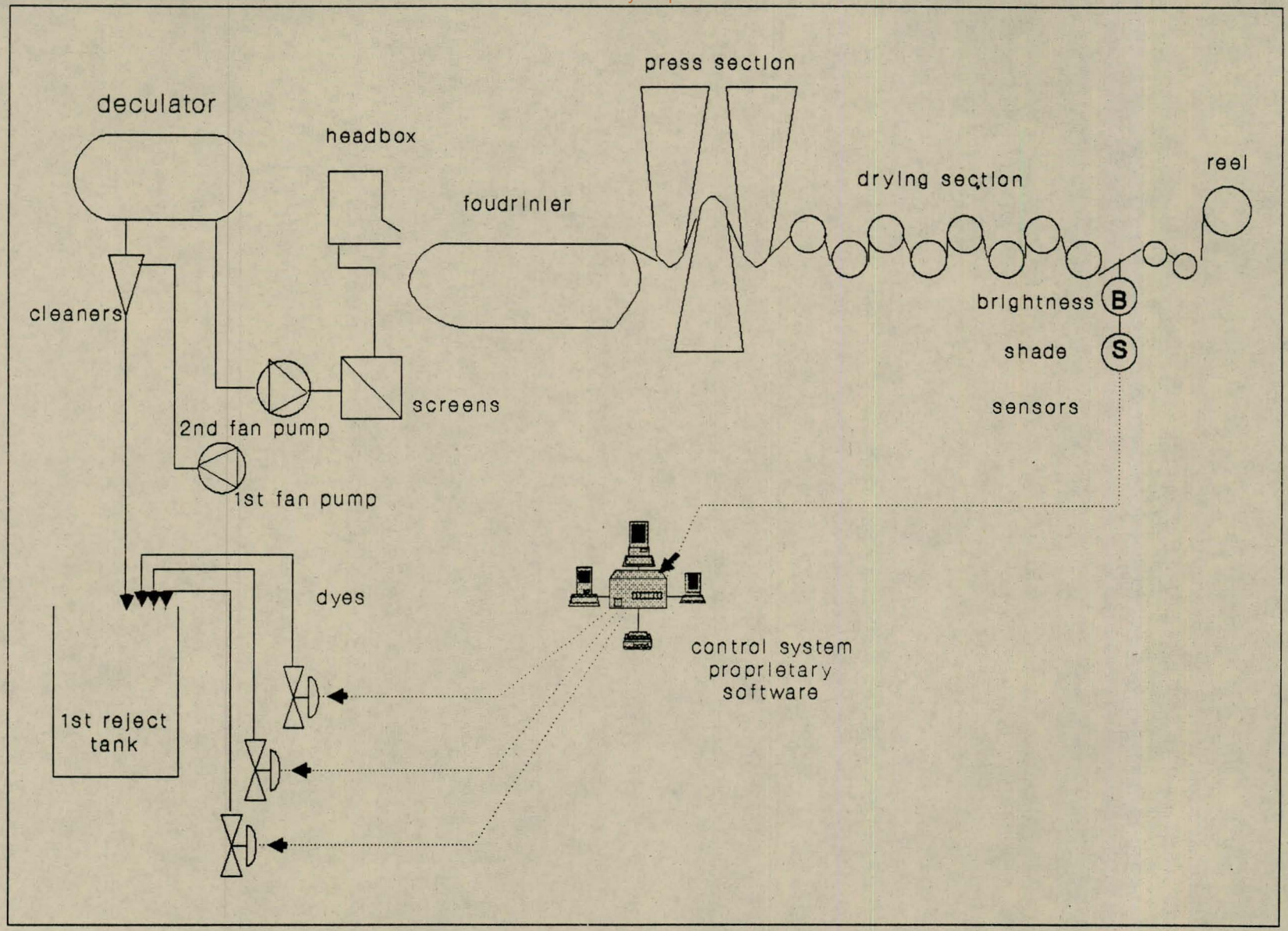


Figure 55 : PAPER MACHINE SHADE CONTROL

3.7 AIR CONTENT

A certain quantity of air is always present within the furnish of the paper machine and occurs in three forms, i.e. free, residual and dissolved, dependent on the quantity (Kurtz 1987). Free air is readily visible as large bubbles and/or foam. Residual air is present in the suspension as tiny bubbles which adhere to the non-wetting surfaces of fibres and other suspended solids. Dissolved air remains in solution in proportion to its solubility at a given temperature, pressure and chemical environment.

The air content of the stock suspension is largely dependent on the properties of the fibre surface and the presence of low-molecular surface active substances in the water. The rate of absorption is mainly due to the interfacial tension between the fibre and the aqueous phase, the electrokinetic charge of the suspended material and the fibre structure. The water repellency resulting from the pitch contained in the fibre furnish and the positive charge are responsible for the adhesion of the air bubbles to the fibres. While free and dissolved air in the stock suspension only plays an insignificant role, residual air has an adverse effect on the production process and the quality of the finished product.

The presence of air and other gases in stock suspensions and their effect on fibre processing has received considerable attention in the paper industry. Figure 56 shows the variations of the fibre suspension properties caused by different air content (Lorz 1987). Much effort has been made in quantifying and evaluating the benefits of stock deaeration (Brecht et al. 1959;

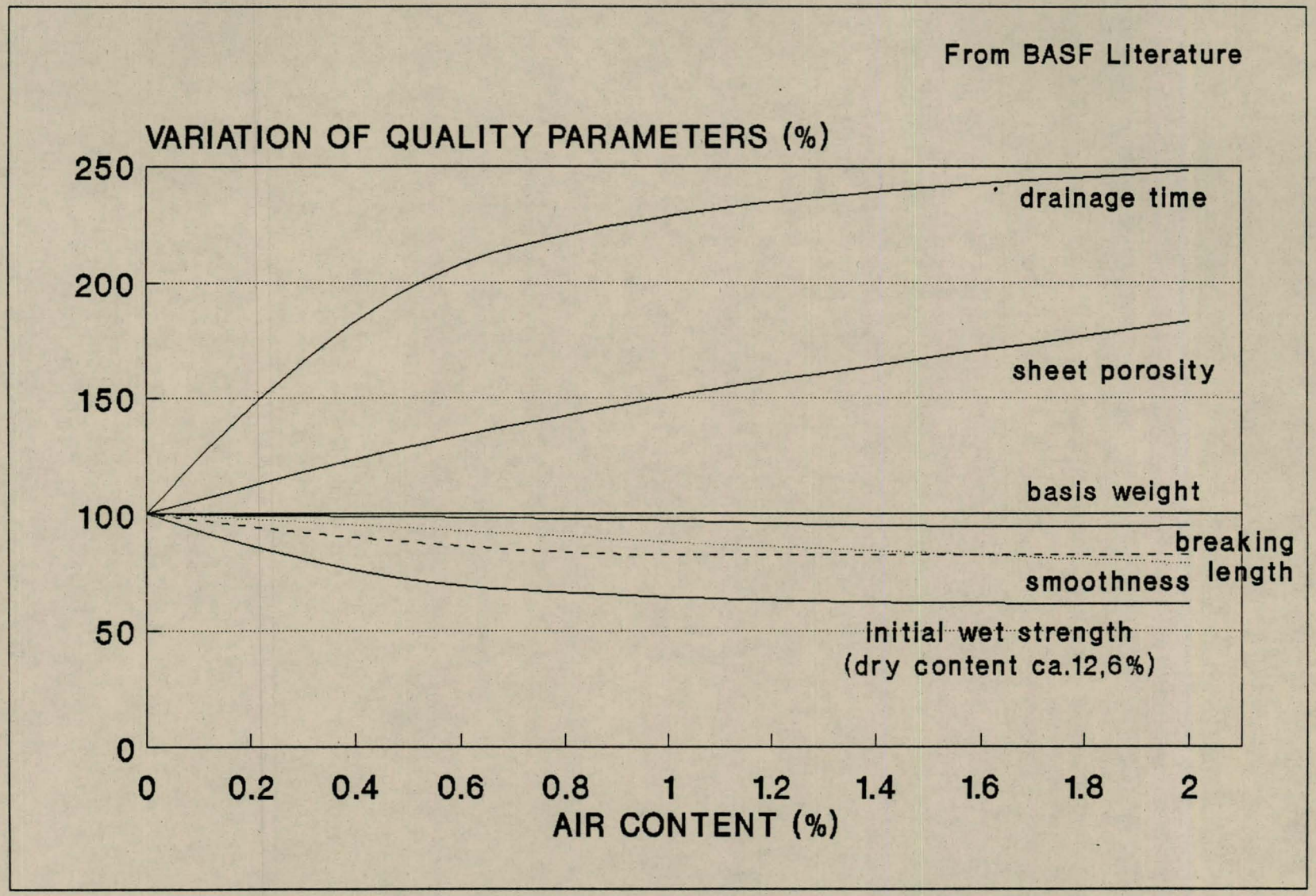


Figure 56 : QUALITY PARAMETERS VARIATION WITH STOCK SUSPENSION AIR CONTENT

May 1967; Sedving 1969; Karras et al. 1989). Increased fibre drainage of deaerated stock suspensions has been a major cost-effective benefit in papermaking (MacGregor 1968).

The amount of entrained air in a pulp suspension can be controlled by taking in consideration details such as process design, equipment maintenance and operating procedures. Mechanical equipment for reducing air content have been developed and are commonly used in mills today, for example the deculator (Benham et al. 1967). It may be necessary to reduce further the air content with special process chemicals, mainly defoamers. Defoamers are surface active chemicals which operate by reducing the stability of air bubbles and foam, causing them to collapse and coalesce (May 1967, May et al. 1975). A surfactant for use as an antifoam must have little affinity for water (therefore a tendency to migrate into the interfacial area) and a positive spreading coefficient relative to the foam formers. However, these chemicals are expensive and an overdosage can reduce the tensile strength of paper (Springer et al. 1985) or cause formation of deposits on the paper machine (Piluso 1977, Allen 1980).

Continuous control of defoamer addition rate has been hampered by the lack of a reliable device for on-line measurement of the air content. Many laboratory methods have been developed (Broadway 1956) and reviewed by Woodworth (1990), but none are suitable for on-line measurement. Other methods developed outside the pulp and paper industry and based on the compressibility theory are cumbersome and have not found use in industry. Two new instruments have recently

been developed, one providing a volumetric measurement of the air content based on sample compressibility (Dougherty 1989) and the other one based on the attenuation of ultrasonic transmission by the air entrained in a suspension (Karras et al. 1988). Each method requires off-line sampling of the lean stock at the headbox and application is still in the experimental stage.

It would still be possible to develop a control strategy for the defoamer flow by supposing that one of the continuous measuring devices will be accurate enough and commercially available in the near future. The antifoams have the advantage that they do not lose their effect on account of the mechanical stock treatment because they always will reaccumulate in the interfacial area. The point of defoamer addition is of great importance. The addition must be far from the headbox so that there is sufficient time for the air to escape upwards. Experience has shown that optimum effects often can be obtained by adding the defoamer to the backwater in the silo.

The instrument for measuring of the headbox lean stock air content will be installed in the headbox recirculation piping (figure 57). Detection of air present in the stock will increase the addition rate of defoamer. Care must be taken to avoid excessive defoamer addition due to unwanted interactions with other process properties. Flow limits with alarms must be installed to ensure that operators will control excessive usage of defoamer which may be caused by breakdown of process equipment rather than changes in the wet end chemistry.

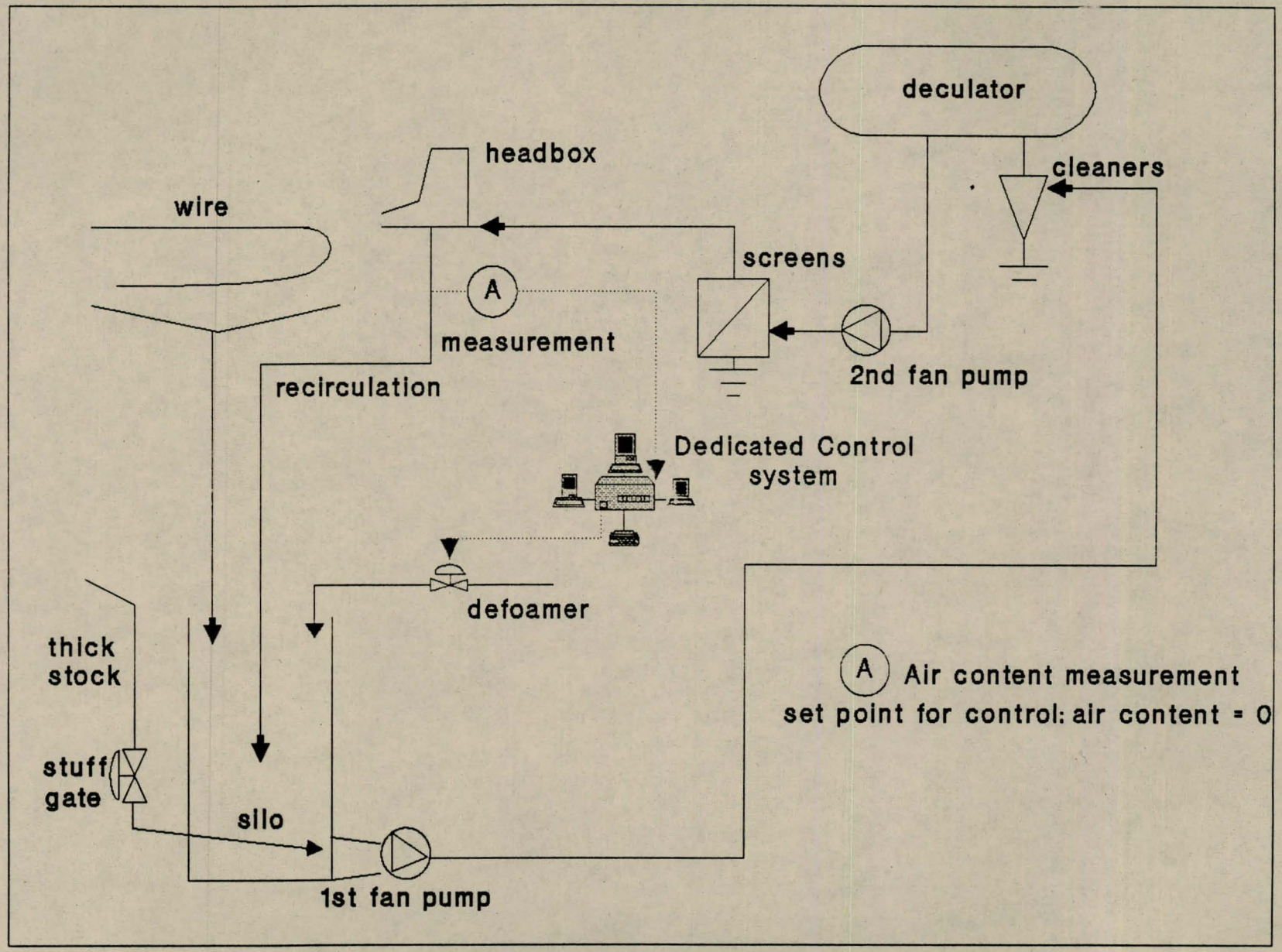


Figure 57 : APPROACH FLOW AIR CONTENT CONTROL

CHAPTER 4

OVERALL CONTROL STRATEGY

The term "Control Strategy" means a strategy for controlling the uniformity of the paper quality produced on the papermachine by acting on the chemicals fed in stock preparation. As quality uniformity and lower process variability are attained, improvements in quality and productivity can be achieved. The main thrust behind the control strategy is that the papermaking system is a dynamic, changing environment and chemical addition rates must be adjusted to compensate for any variations.

Retention control strategy models have been proposed by Lindstrom et al. (1984), Scott (1984), Springer et al. (1985) concentrating on consistency and charge measurements in the thin stock area. A more comprehensive approach was proposed by Nobel (1985) and Springer et al. (1987) with sensors placed in the stock preparation area, but still focusing on first pass retention control. This first pass retention control approach is based on the following assumptions:

a) that the wet end chemistry performance is dependent on the first pass retention level achieved;

b) that retention aids are necessary to obtain acceptable first pass retention levels and adequate drainage on high speed machines;

c) that anionic interfering substances impair the effectiveness of the cationic additives and paper properties.

One problem in optimising the control strategy is the variable chemical and physical interactions of the stock. Flocculation, for example, is not only dependent on stock consistency, stock

temperature, types of fibre and composition of the stock, but also on freeness, pH and the levels of filler, alum and retention aid addition (Melzer et al. 1988). It is recommended to start implementing the control loops discussed previously and optimise the control logic by gathering process data. New instruments or more accurate ones will be developed in the mean time and it will be possible to expand or improve the control loops (Kortelainen 1992).

It is intended to develop a control strategy similar to the one described by Springer et al. (1985) without considering wet end ash control, but expanding it to the entire stock preparation system and integrating the various concepts proposed previously (figure 54). We will start by the thin stock loops (figure 55).

Sheet formation, machine dewatering capacity, stock drainage and fibre retention will determine headbox consistency. No on-line instruments are yet commercially available to measure the first three parameters. Sheet formation has received considerable attention lately and accurate on-line sensors should be available in the near future. This should help the papermaker to evaluate floc formation. The second parameter could be measured either by the position of the sheet dry-line, recorded vaccum in the vacuum boxes, near infra-red sensing or sonic measurement of the thickness of the water layer at a certain point on the draining table. For the third parameter, a drainage/freeness analyser could be installed at the headbox recirculation pipe, but no accurate sensor is yet available. The headbox consistency will be measured using the Kajaani LC100 (or low consistency meter) sampling from the headbox recirculation pipe (Figure 30).

The silo consistency will then be recorded with a low consistency

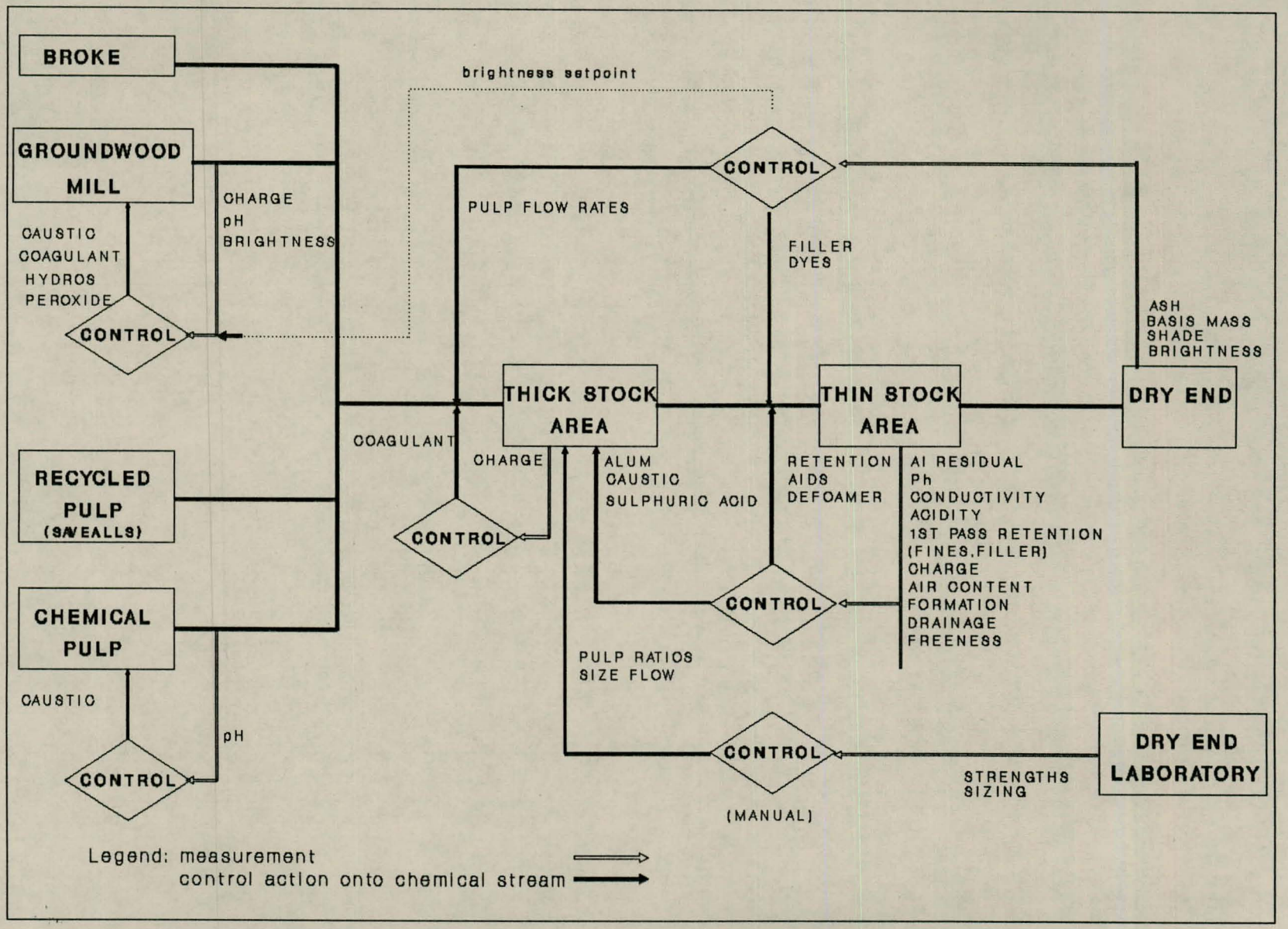


Figure 58 : OVERALL CONTROL STRATEGY OF CHEMICALS IN STOCK PREPARATION

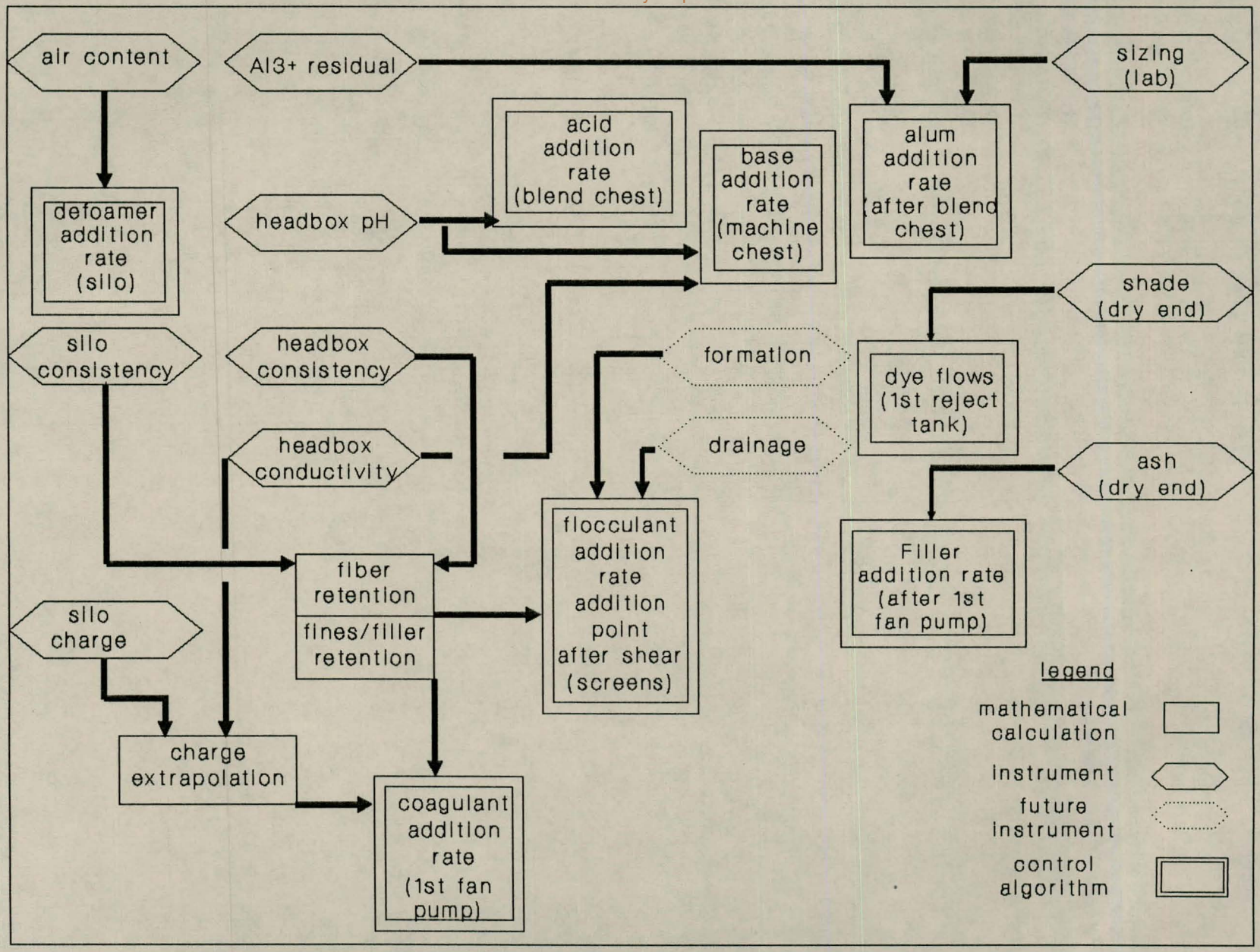


Figure 59 : THIN STOCK AREA CONTROL STRATEGY

meter and the fibre-filler retention calculated. The fibre retention value together with formation, headbox consistency, flocculant to production rate ratio and coagulant to flocculant ratio will determine the addition rate of the high molecular weight flocculant required. This will allow for an uniform fibre retention level as well as micro-floc formation and drainage rate. Generally, good results can be obtained when the flocculant is added to the headbox approach flow piping as the shearing actions of refiners and stock pumps are so severe as to destroy the formed flocs even with the use of polymers with high charge density. The fines-filler retention will then control the low molecular weight coagulant addition rate to pretreat the fines before addition of the filler (Waesch 1983). The coagulant can be added before the first fan pump to ensure mixing and adsorption on to the fines and fibers before addition of the filler. The filler addition rate is controlled by the dry end ash sensor and is added just before the deculator or the second fan pump. The colloidal charge of the silo furnish measured with the streaming current detector and adjusted to a preset conductivity value, will indicate if an increase/decrease of the addition rate of the coagulant is necessary.

In a second loop, the headbox air content will control the amount of defoamer added at the silo. This could be linked to a hole detector installed at the dry end of the machine and the randomly determined number of pin holes could be fed back to the control loop to optimise the addition rate.

The third loop will comprise the measurement of headbox pH, acidity and residual aluminium ion content with control of the chemicals in the thick stock area. pH and acidity will control the amount of caustic and sulphuric acid added into the blend chest. The residual aluminium ion level will control the addition rate of

alum to the blend chest. With the size flow rate, which is controlled manually via the dry end laboratory sizing results, the size to alum ratio will be calculated and compared to set limits for achieving optimum sizing results.

The last two control loops in the thin stock area will receive the control signal via the dry end, i.e. the filler flow rate control via the dry end ash sensor and the dye stuff flow rate via the shade/brightness sensor. The ash control loop has been in use for a few decades and proprietary software and hardware are available on the market. From the dry end shade/brightness sensor, the addition rate into the first stage cleaner reject tank of the dye stuff (generally 2 to 3 dyes) will be controlled. When the brightness value approaches the control limits (high or low), a signal is sent to the brightness controller in the pulp plant to adjust the setpoint in the opposite side. Care must be taken due to the lag time as a result of the pulp storage volumes.

In the thick stock area, apart from the control of the pulp flow rate by the dry end mass sensor and machine speed, and the pulp stream ratios which are controlled by the paper strength, the only other control loop is the charge neutralization of anionic organic contaminants with a low molecular weight, high charge density polymer. The stock charge will be measured after the machine chest, corrected for conductivity changes and will control the coagulant flow rate added to the machine chest. The development of an instrument for on-line determination of paper strength will enable to adjust the ratio of the pulp streams to optimise strength, optical properties and cost. Some interesting results were obtained by using near-infrared light (Durgueil 1990) for the determination of paper strength, i.e. tear and burst of newsprint, using different furnishes and paper machines. More work is

required as well as the development of a sizing measurement sensor for full automation of the strategy.

The last loops are situated in the pulp plant. pH will be controlled during the chemical pulp preparation and in the groundwood mill. A link with the headbox acidity measurement may optimise cost. As the system closes up with the machine running continuously, acidity tends to increase and controlling it by increasing the alkalinity of the chemical pulp and reducing the acidity of the groundwood mill may save on chemical usage, as well as reduce corrosion in the thick stock area. Neutralization of the contaminants in the groundwood mill will be carried out by measuring the stock charge after pulping and adding a low molecular weight, high charge density coagulant into the grinder showering system and the grinder flume.

Pulp brightness in the groundwood mill will be controlled as discussed earlier and depending on the bleaching process used.

CHAPTER 5

CONCLUSION

Papermaking wet end chemistry will become an even more important component of quality management in the future. Recent advances in sensor technology to measure wet end chemical variables have made it possible to control properties on-line. Control loop design and implementation will result in improvement in papermaking chemistry uniformity and hence in paper quality. The addition of wet end chemicals will change to a more scientific approach.

To properly maintain wet end chemistry uniformity, it is recommended that the following parameters should be controlled:

(i) pH should be measured and controlled in the pulp preparation area and the various control loops with the setpoint for optimum process performance were discussed;

(ii) acidity in the approach flow piping must be controlled. A method to determine acidity from conductivity and pH measurements was proposed and the control procedure was discussed;

(iii) if alum is used in the process as a retention aid or for sizing purposes, the residual aluminium ion levels must be monitored to avoid problems with overusage. Measurement of the residual aluminium ion content using the fluoride ion selective electrode technique was reviewed and an instrument was designed for continuous on-line monitoring. Alum should only be used in the approach flow piping and the control loop was presented;

(iv) retention has been discussed extensively in the literature and it is an essential tool for the papermaker to monitor the operation of the machine. The Kajaani LC100 low consistency transmitter

was used during the investigation to determine the consistency and ash content of the silo and headbox white water. Due to the influence of furnish type and ash content of the white water on the accuracy of the measurement, the signal processing was modified which allowed to accurately measure the consistency and ash content of the white water over a wide range of solids content, ash content and different furnish types. The instrument was able to accurately determine the consistency, fibre and ash retentions on-line;

v) the use of the streaming current detector to measure surface charge was evaluated and the influence of conductivity and pH on the measurement is discussed. The sample of white water to be measured by this instrument has to be filtrated, and an on-line filter system was designed. The retention control philosophy using the low consistency transmitter and the streaming current detector is discussed;

vi) paper brightness and shade control are important quality parameters. A brightness sensor was installed in the TMP plant and the process conditions before and after the modification are presented as well as the financial benefits of pulp brightness control. The basic control loops for the operation of a bleach plant are reviewed. The need for control of paper shade at the paper machine is highlighted and the control loop is presented;

vii) the negative influence of stock aeration on paper properties is reviewed. No instrument is yet commercially available to measure on-line the air content in the white water. The control loop to regulate the addition rate of defoamer is discussed.

Not all of the instruments necessary to implement the control strategy have reached a state of development to be accurate enough. It is up to the individual papermaker to implement control loops step by step, using the existing instruments and develop

new ones with the help of the instrument and control system suppliers.

Optimisation of the wet end begins with monitoring the parameters which reflect its variability and understanding the relationship between them. It will be possible to relate these parameters to paper quality measurements or variability. Eventually, the entire papermaking control system can be integrated into one functional package with the aim to improve paper uniformity and quality.

APPENDIX 1

pH MEASUREMENTS

CHEMICAL PULP BEATING AT DIFFERENT pHs

1) Change in freeness at different pHs

beating time (min)	freeness (ml CSF)			
	pH : 8,0	pH : 7,1	pH : 5,5	pH : 4,5
0	737	740	735	740
2	731	732	730	740
22	643	657	620	675
42	565	530	460	497
62	470	332	277	320
82	364	197	172	117
102	295	132	112	117

2) Pulp strength with beating at different pHs: tear index

Freeness (ml CSF)	Tear index (mN.m2/g)			
	pH : 8,0	pH : 7,1	pH : 5,5	pH : 4,5
740		16.61		15.88
740				23.46
737	18.74			
735			15.09	
732		22.67		
731	23.72			
730			21.8	
675				17.26
657		14.87		
643	17.02			
620			13.22	
565	15.12			
530		12.73		
497				14.08
470	14.26			
460			12.73	
364	13.94			
332		11.21		
320				12.9
295	13.6			
277			11.86	
197		10.72		
172			11.91	
157				11.88
132		10.63		
117				11.8
112			11.05	

3) Pulp strength with beating at different pHs: tensile index

Freeness (ml CSF)	Tensile index (Nm/g)			
	pH : 8,0	pH : 7,1	pH : 5,5	pH : 4,5
740		24.22		20.34
740				26.95
737	21.01			
735			21.39	
732		36.67		
731	30.77			
730			39.15	
675				63.26
657		63.28		
643	68.07			
620			82.45	
565	73.34			
530		82.41		
497				80.75
470	83.56			
460			85.65	
364	93			
332		89.61		
320				88.2
295	93.29			
277			96.63	
197		99.42		
172			100.56	
157				88.61
132		106.1		
117				91.22
112			95.75	

4) Pulp strength with beating at different pHs: burst index

Freeness (ml CSF)	Burst index (kPa.m2/g)			
	pH : 8,0	pH : 7,1	pH : 5,5	pH : 4,5
740		1.22		1.12
740				1.49
737	1.37			
735			1.08	
732		2.37		
731	2.19			
730			2.47	
675				4.93
657		5.63		
643	5.54			
620			6.31	
565	6.4			
530		6.03		
497				6.87
470	6.9			
460			7.27	
364	7.41			
332		7.81		
320				7.79
295	7.65			
277			7.81	
197		7.33		
172			7.95	
157				7.62
132		7.9		
117				8.05
112			7.69	

pH VARIATION OF CHEMICAL PULP IN HYDRAPULPER

Paper machine 1 - Figure 7

DAY 1

sampling time	pH of stock
6 : 0	7.5
6 : 30	7.5
7 : 0	6.6
7 : 30	6.9
8 : 0	7.3
8 : 30	7.8
9 : 0	7.4
9 : 30	7.3
10 : 0	7.4
10 : 30	7.3
11 : 0	7.5
11 : 30	7.4
12 : 0	7.6
12 : 30	7.4
13 : 0	7.2
13 : 30	7.3
14 : 0	7.3
14 : 30	7
15 : 0	7.2
15 : 30	7.5
16 : 0	7
16 : 30	6.7
17 : 0	7.4
17 : 30	7.2
18 : 0	7.2
18 : 30	7.3
19 : 0	8
19 : 30	8.2
20 : 0	8.5
20 : 30	8.4
21 : 0	9
21 : 30	8.7
22 : 0	8.4
22 : 30	7
23 : 0	6.8
23 : 30	7.2

DAY 2

sampling time	pH of stock
0 : 0	6.5
0 : 30	6.9
1 : 0	7
1 : 30	6.3
2 : 0	6.7
2 : 30	6.8
3 : 0	7.1
3 : 30	7.3
4 : 0	6.9
4 : 30	7.1
5 : 0	7.3
5 : 30	7
6 : 0	7.2
6 : 30	7.3
7 : 0	8
7 : 30	8.2
8 : 0	7.8
8 : 30	7.9
9 : 0	7.8
9 : 30	7.6
10 : 0	6.9
10 : 30	7.3
11 : 0	7
11 : 30	6.5
12 : 0	7.5
12 : 30	7
13 : 0	7.2
13 : 30	6.7
14 : 0	6.8
14 : 30	7
15 : 0	7
15 : 30	6.8
16 : 0	7.3
16 : 30	6.9
17 : 0	7.1
17 : 30	7
18 : 0	7.3
18 : 30	6.4
19 : 0	6.3
19 : 30	7
20 : 0	7.3
20 : 30	7.5
21 : 0	7.5
21 : 30	7.7
22 : 0	8
22 : 30	7.5
23 : 0	7.2
23 : 30	7.3

DAY 3

sampling time	pH of stock
0 : 0	7.4
0 : 30	7.2
1 : 0	7
1 : 30	7.2
2 : 0	6.5
2 : 30	6.8

AVERAGE pH : 7,23
STANDARD DEVIATION: 0,68

APPENDIX 2

CONDUCTIVITY AND ACIDITY MEASUREMENTS

CONDUCTIVITY VERSUS ALUM CONCENTRATION IN SOLUTION

Figure 15

ALUM CONCENTRATION (PPM)	SOLUTION CONDUCTIVITY (µS/cm)
0	2
2	8
5	14
10	22
15	31
20	41
30	52
40	64
50	78
75	108
100	138

Distiiled water solution. Alum content checked by colorimetric method.

ACIDITY AND CONDUCTIVITY RELATIONSHIP

Figure 16
Stock from newsprint, fine paper and part-mechanical paper machines taken randomly at the headbox sampling point.
Stock pH constant at 4,4 +/- 0,1

sample acidity (ppm CaCO3) (end pH 8,3)	sample conductivity (µS/cm)
20	1070
30	1110
50	1500
50	1785
55	1460
55	1320
65	1450
71	880
76	1560
82	1490
90	1900
95	620
95	1450
96	2380
100	1630
100	2180
106	1320
110	1680
110	2200
110	2290
127	1610
127	1870
127	2100
129	1910
138	2100
140	1900
142	2020
146	1990
146	2090
155	2010
160	1980
160	2060
180	2150
185	1400
200	2490
200	2580
204	2470
215	2760
225	2390
295	2050
316	2590

ACIDITY AND pH INDEPENDENCE in an ALUM based SOLUTION

Figure 17
Stock from newsprint, fine paper and part-mechanical paper machines running alum based chemistry. Samples of white water from headbox filtered in the laboratory.

sample acidity (µS/cm)	sample pH
15	5.8
20	4.4
20	4.6
25	4.6
30	4.5
35	4.5
35	4.6
35	5.1
40	4.9
45	4.6
50	4.5
55	4.5
55	4.9
60	4.8
60	4.7
63	4.4
68	4.4
70	4.6
78	4.4
78	4.8
78	5.1
80	4.8
80	4.6
85	4.7
90	4.5
100	4.6
100	4.4
100	4.2
100	5
105	4.4
110	4.3
110	4.2
120	4.3
140	4.2
145	4.5
150	4.2
160	4.3
160	4.8
160	5
170	4.5

sample acidity (µS/cm)	sample pH
180	4.1
180	4.7
190	4.1
195	4.7
200	4.1
200	4.7
200	4.5
200	4.4
205	4.7
205	4.6
205	4.2
205	4.4
215	4
220	4.5
225	4
230	4.2
245	4
245	4.4
255	4.4
260	4.1
265	4.1
280	4.1
285	4
285	4.3
295	4.4
300	4.2
300	4.5
315	4.1
315	4.4
325	4.2
390	3.9

ON-LINE VERSUS LABORATORY CONDUCTIVITY MEASUREMENTS

Figure 18
Stock from the headbox of paper machine 3 on part-mechanical paper grades.

laboratory sample conductivity (µS/cm)	on-line sample conductivity (µS/cm)
3200	3300
3240	3300
3180	3300
2100	1900
1980	1900
1232	900
1280	1000
1232	1000
1350	1100
2150	2000
2120	1900
1980	2000
2230	2150
2500	2300
3580	3500
3250	3200
3240	3200
2780	2800
4080	4100
3240	3600
3210	3600
2750	2950
3000	3000
2000	1900
2410	2450
2840	2800
2900	2850
2930	2900
3110	3100
3200	3300
1450	1400
1340	1350
1600	1600
1308	1200

ACIDITY DETERMINATION FROM ON-LINE pH and CONDUCTIVITY MEASUREMENTS

Figure 19
Samples from Papermachine 3 headbox. Paper grades: Text, Tablet, Xerox-Bond, Bank
Equation: Calculated Acidity = exp(-1,418xpH+0,00125xConductivity+7,83)

date	pH	conductivity (uS/cm)	laboratory acidity (ppm CaCO3	calculated acidity (ppm CaCO3)
6/3/92	4.30	1200	20	26
	4.30	1200	40	26
	4.10	1200	34	34
	4.10	1200	40	34
	4.20	1200	51	29
7/3/92	4.10	1100	60	30
	4.00	1200	64	39
	4.00	1100	56	34
	4.20	1200	48	29
8/3/92	4.40	1000	16	17
	4.50	1000	14	15
	4.50	900	16	13
	4.30	1100	20	23
	4.10	1200	32	34
9/3/92	4.40	1300	15	25
	4.30	1300	24	29
	4.20	1300	35	33
	4.10	1300	59	38
	4.00	1500	61	57
	4.10	1700	57	63
	4.10	1600	62	56
	4.10	1600	58	56
	4.30	1800	80	54
	4.40	1600	74	37
	4.40	1500	71	32
12/3/92	4.00	1400	169	50
	4.00	1400	110	50
13/3/92	4.00	1900	165	94
	4.50	2300	130	76
	4.50	2500	190	98
	4.40	2500	204	113
	4.30	2800	260	189
	4.30	2700	195	167
14/3/92	4.50	2800	160	142
	4.60	2600	105	96
	4.60	2600	120	96
	4.30	2500	148	130
15/3/92	4.50	2500	110	98
	4.40	2500	127	113
	4.50	2500	114	98
	4.70	3200	160	177
	4.60	3200	166	204
	4.30	2800	140	189
16/3/92	4.50	2400	100	86
	4.40	2500	104	113
	4.40	2400	89	99

Regression Output:

Constant		7.83505
Std Err of Y Est		0.21524
R Squared		0.64628
No. of Observations		71
Degrees of Freedom		68
X Coefficient(s)	-1.418	0.00125
Std Err of Coef.	0.3238	0.00011

date	pH	conductivity (uS/cm)	laboratory acidity (ppm CaCO3	calculated acidity (ppm CaCO3)
16/3/92	4.50	2600	78	111
	4.30	1900	67	61
17/3/92	4.20	2800	140	218
	4.50	2400	100	86
	4.50	2500	104	98
	4.50	2400	89	86
	4.70	2600	78	84
	4.30	2000	67	69
18/3/92	4.20	2200	80	103
	4.10	1700	76	63
	4.20	1800	88	62
	4.20	2000	92	80
	4.00	1700	109	73
	4.10	1600	15	56
20/3/92	4.00	1600	20	64
	4.10	1600	20	56
	4.00	2000	31	106
22/3/91	3.90	1900	37	108
	4.20	1400	19	38
23/3/92	4.10	1300	19	38
	4.20	1200	25	29
	4.50	1400	8	25
	4.50	1400	10	25
	4.60	1400	15	21
	4.90	1400	10	14
24/3/92	5.50	1100	27	4
	5.80	1100	45	3
	4.80	1200	12	13
	5.20	1200	10	7
25/3/92	4.70	1300	28	16
	4.70	1400	24	19
	4.70	1400	20	19
	5.00	1300	31	11
	5.20	1500	20	10
	5.10	1400	28	11
26/3/92	4.70	1400	35	19
	4.60	1300	21	19
	4.30	1200	12	26
	4.30	1400	20	33
	4.30	1400	15	33
	4.10	1500	18	49
27/3/92	4.10	1400	28	44
	4.10	1500	40	49
	4.10	1500	16	49
	4.10	1500	20	49
	4.30	1500	24	37
	4.20	1500	28	43
28/3/92	4.10	1600	39	56
	4.10	1600	60	56
	4.10	1600	14	56
	4.20	1600	20	49
	4.10	1400	38	44
	4.10	1600	35	56

date	pH	conductivity (uS/cm)	laboratory acidity (ppm CaCO3	calculated acidity (ppm CaCO3)
29/3/92	4.10	1600	40	56
	4.20	1600	28	49
30/3/92	4.30	1600	46	42
	4.20	1600	40	49
31/3/92	4.20	1400	14	38
	4.10	1200	24	34
	4.00	1200	12	39
	4.20	1100	19	26
	4.00	1000	8	30
1/4/92	4.00	1000	10	30
	4.80	1200	5	13
	4.70	1300	8	16
	4.80	1300	10	14
	4.70	1200	10	14
	4.80	1200	6	13
2/4/92	4.80	1400	9	16
	4.10	1500	6	49
	4.20	1600	5	49
	4.10	1600	10	56
	4.00	1400	10	50
	4.00	1500	15	57
	4.10	1600	9	56
3/4/92	4.60	1600	23	28
	4.70	1000	10	11
	4.80	1500	4	18
	4.50	1600	10	32
	4.20	1400	18	38
	4.30	1500	10	37
4/4/92	4.10	1300	19	38
	4.60	1400	14	21
	4.60	1400	28	21
	4.60	1400	30	21
	4.40	1400	30	28
	4.40	1200	25	22
	4.40	1400	33	28
5/4/92	4.40	1300	69	25
	4.30	1500	56	37
	4.40	1500	64	32
	4.30	1400	76	33
	4.20	1200	68	29
	4.40	1200	79	22
6/4/92	4.40	2500	78	113
	4.20	2600	66	170
	4.20	2600	74	170
	4.20	2600	70	170
	4.40	2400	50	99
	4.40	2500	56	113
7/4/92	4.50	2500	25	98
	4.40	1600	30	37
	4.40	1600	38	37
	4.40	1500	38	32
8/4/92	4.30	1500	20	37
9/4/92	4.50	1800	30	41
	4.50	1900	42	46

date	pH	conductivity (uS/cm)	laboratory acidity (ppm CaCO3	calculated acidity (ppm CaCO3)
9/4/92	4.80	2200	30	44
	4.40	2000	48	60
	4.70	2600	50	84
	4.40	2500	59	113
13/4/92	4.20	1400	50	38
	4.20	1500	66	43
	4.20	1400	35	38
	4.30	1500	30	37
14/4/92	4.20	1400	20	38
	4.70	1300	10	16
	4.60	1500	16	24
	4.60	1500	15	24
	4.40	1500	23	32
	4.20	1200	20	29
15/4/92	4.60	1400	36	21
	4.50	1500	43	28
	4.40	1300	40	25
	4.30	1400	34	33
	4.20	1400	28	38
16/4/92	4.30	1500	36	37
	4.20	1600	35	49
	4.40	1500	28	32
	4.40	1500	26	32
	4.30	1500	38	37
	4.30	1500	22	37
17/4/92	4.20	1400	22	38
	4.20	1600	17	49
	4.40	1500	20	32
	4.40	1400	17	28
	4.40	1300	41	25
	4.30	1400	26	33
18/4/92	4.40	1300	28	25
	4.30	1500	35	37
	4.30	1400	30	33
	4.30	1300	22	29
	4.30	1300	26	29
	4.30	1400	28	33
19/4/92	4.40	1500	35	32
	4.20	1200	30	29
	4.30	1600	39	42
	4.50	1100	37	17
20/4/92	4.40	1500	38	32
	4.50	1500	12	28
	4.60	1500	18	24
	4.50	1400	26	25
	4.30	1400	15	33

APPENDIX 3

RESIDUAL ALUMINIUM ION DETERMINATION USING FLUORIDE SELECTIVE ELECTRODE

RESIDUAL ALUMINIUM DETERMINATION USING FLUORIDE SELECTIVE ELECTRODE

Figure 22
The fluoride ion selective electrode method is used to determine the aluminium ion concentration in solution by back titration.

Method
Prepare solution of aluminium ions ranging from 0 to 20 mg/l Al3+ with increments of 2,5mg/l.
Mix 50 ml of Al3+ solution with 50 ml of Sodium fluoride (NaF 0,001M)/ buffer mixture in a 250ml beaker (magnetic stirrer).
Insert fluoride selective electrode, reference electrode and temperature compensation probe in beaker while stirring.
Record potential on pH meter.

Reagents:
buffer: 14,4ml Glacial Acetic acid;
26,9g Sodium Perchlorate
6,52g Sodium Acetate Trihydrate
diluted to 200 ml with deionized water
Sodium fluoride solution: 0,042g NaF diluted to a litre (0,001M)

aluminium concentration (al3+ ppm)	electrode potential (mV)					
	reading 1	reading 2	reading 3	reading 4	reading 5	average
0.0	94.8	94.8	95.7	95.6	95.9	95.4
2.5	101.8	102.2	102.2	102.5	102.9	102.3
5.0	110.9	110.8	111.6	111.3	112.1	111.3
7.5	122.6	122.4	122.4	121.9	123.6	122.6
10.0	136.5	136.5	137.0	136.7	137.6	136.9
12.5	154.3	154.3	154.4	154.7	154.5	154.4
15.0	171.2	172.3	173.2	169.7	171.3	171.5
17.5	189.9	188.1	186.9	187.8	187.2	188.0
20.0	198.4	199.0	198.6	198.6	198.9	198.7

Standard deviation for measurement: 0,66 mV
Regression for best fit curve:
$Al3+ = 1{,}629 \times Pot - 0{,}0096 \times Pot^2 + 0{,}0000243 \times Pot^3 - 85{,}889$
with Pot : electrode potential (mV)
Al3+ : aluminium ion concentration (ppm)
regression coefficient (R^2) : 99,99%

APPENDIX 4

KAJAANI LC100 EVALUATION MEASUREMENTS

CALIBRATION CURVE FOR KAJAANI LC100

Figure 26
Procedure as per Kajaani handbook, with white water from paper machine 1, paper grade news 48,8 g/m2.
Ash content constant at +/- 4,7%.

WHITE WATER CONSISTENCY (%)	KAJAANI LC100 OUTPUT VOLTAGE READING (V)
0.07	0.44
0.11	0.50
0.16	0.61
0.17	0.58
0.23	0.69
0.26	0.83
0.30	0.78
0.32	1.00
0.34	0.89
0.45	1.33
0.60	1.89
0.70	2.20
0.78	2.44
0.79	2.67
0.87	2.97
0.91	2.94
1.02	3.36
1.20	3.92
1.43	4.44

Regression Analysis

Intercept	-0.0012
Slope	0.3113
R^2	0.9912
Sum X^2	91.8152
Sum Y^2	8.8953
Sum X*Y	28.5378

C% = -0,0012 + 0,3113 x V

with
C% : white water consistency (%)
V : instrument output voltage

KAJAANI LC100 CALIBRATION CHANGE WITH WHITE WATER ASH CONTENT

Figure 27
Procedure as per Kajaani handbook, with white water from paper machine 1, paper grade news 48,8 g/m2.
Ash content increased by addition of clay slurry and ash content of sample measured as per Tappi Standards.
Sample consistency kept constant at +/- 1,1%.

WHITE WATER ASH CONTENT (%)	KAJAANI LC100 OUTPUT VOLTAGE READING (V)
4.00	3.63
4.20	3.57
4.20	3.67
14.50	3.02
24.60	2.77
40.00	2.25
53.40	1.66

Regression Analysis

Intercept	3.7446
Slope	-0.0389
R^2	0.9889
Sum X^2	5318.2500
Sum Y^2	64.0021
Sum X*Y	335.5040

V = 3,7446 - 0,0389 x Ash%
with
Ash% : white water ash content as a fraction of solids (%)
V : instrument output voltage

The slope is negative due to the increase in the sample turbidity and increased light absorption by the clay particles.

KAJAANI LC100 CALIBRATION CHANGE WITH WHITE WATER FIBRE SIZE

Figure 28
Procedure as per Kajaani handbook, with white water from paper machine 1. GWD, TMP, Chemical Pulp samples and pulp mixtures diluted with white water to a consistency of +/- 1,2%. Samples fibre sizes measured using Kajaani FS100. Ash content of samples constant at +/- 4,7%.

WHITE WATER WEIGHTED AVERAGE FIBER SIZE (mm)	KAJAANI LC100 OUTPUT VOLTAGE READING (V)
0.70	4.18
0.81	4.35
0.91	4.49
0.97	4.49
1.07	5.34
1.18	5.14
1.40	4.29
1.47	5.70
1.66	5.82
1.87	7.33

Regression Analysis

Intercept	2.5210
Slope	2.1528
R^2	0.7069
Sum X^2	15.8258
Sum Y^2	270.1457
Sum X*Y	64.4230

V = 2.5210 + 2.1528 x Size

with
Size : white water weighted averag fiber size (mm)
V : instrument output voltage

The slope is positive due to the increase in the light depolarization with the increased fibre size, i.e. depolarizing surface area.

KAJAANI LC100 EVALUATION

FOR THE MEASUREMENT OF CONSISTENCIES

DATE	PAPER GRADE	SAMPLE SOURCE	KAJAANI SIGNA		LABORATORY MEASUREMEN			CALCULATED VALUES			RETENTION VALUES			
											FROM LAB. DATA		FROM KAJAANI SIGNALS	
			Vcs	Vref	C (%)	ASH (%)	TOTAL ASH (ppm)	FIGURE 31 C (%)	FIGURE 32 TOTAL ASH (ppm)	FIGURE 33 ASH (%)	SOLIDS (%)	ASH (%)	FIGURE 35 SOLIDS (%)	FIGURE 36 ASH (%)
10/7/92	TEXT 60	HEADBOX	3.02	1203	0.75	16.60	1241.85	0.74	1270.70	9.44	42.93	23.67	40.92	13.76
10/7/92	TEXT 60	SILO	1.71	1490	0.47	22.20	1053.17	0.49	1217.61	5.94				
10/7/92	TEXT 60	HEADBOX	2.80	1198	0.74	16.00	1182.08	0.72	1301.53	9.42	38.09	11.01	38.48	16.32
10/7/92	TEXT 60	SILO	1.77	1488	0.51	23.00	1168.86	0.49	1210.11	5.98				
10/7/92	TEXT 60	HEADBOX	2.88	1230	0.80	13.36	1073.48	0.71	1264.56	9.04	45.97	33.19	42.54	18.70
10/7/92	TEXT 60	SILO	1.72	1590	0.48	16.52	796.92	0.46	1142.32	5.21				
10/7/92	TEXT 60	HEADBOX	2.92	1220	0.74	13.77	1016.91	0.72	1268.20	9.18	43.61	31.57	39.58	16.24
10/7/92	TEXT 60	SILO	1.80	1522	0.46	16.71	773.17	0.49	1180.26	5.74				
15/7/92	TABLET 65	HEADBOX	2.80	2054	0.45	11.73	527.97	0.46	577.01	2.64	48.41	39.48	44.81	18.11
15/7/92	TABLET 65	SILO	1.65	2450	0.26	13.76	355.01	0.28	525.00	1.47				
15/7/92	TABLET 65	HEADBOX	3.00	2010	0.47	10.25	481.95	0.49	573.85	2.78	54.66	39.44	51.69	29.39
15/7/92	TABLET 65	SILO	1.60	2570	0.24	13.69	324.32	0.26	450.21	1.17				
15/7/92	TABLET 65	HEADBOX	2.92	2045	0.47	10.80	511.92	0.47	559.97	2.63	54.43	41.27	52.50	32.75
15/7/92	TABLET 65	SILO	1.55	2632	0.24	13.92	334.08	0.25	418.44	1.04				
17/7/92	TABLET 58	HEADBOX	2.80	2082	0.48	11.20	533.79	0.45	553.31	2.50	49.26	29.33	47.88	25.59
17/7/92	TABLET 58	SILO	1.60	2560	0.27	15.60	419.17	0.26	457.47	1.20				
20/7/92	TABLET 58	HEADBOX	2.90	1496	0.57	23.40	1340.35	0.61	1034.27	6.27	36.08	12.05	42.14	14.35
20/7/92	TABLET 58	SILO	1.66	1819	0.41	32.20	1309.90	0.39	984.32	3.84				
20/7/92	TABLET 58	HEADBOX	2.81	1546	0.56	21.00	1183.77	0.58	1005.43	5.84	40.06	11.81	43.59	20.19
20/7/92	TABLET 58	SILO	1.67	1943	0.38	30.90	1159.99	0.36	891.62	3.24				
20/7/92	TABLET 58	HEADBOX	3.00	1485	0.64	19.40	1233.84	0.62	1028.77	6.38	45.09	14.53	42.53	16.59
20/7/92	TABLET 58	SILO	1.76	1836	0.39	30.20	1171.76	0.40	953.43	3.77				

DATE	PAPER GRADE	SAMPLE SOURCE	KAJAANI SIGNA		LABORATORY MEASUREMEN			CALCULATED VALUES			RETENTION VALUES			
											FROM LAB. DATA		FROM KAJAANI SIGNALS	
			Vcs	Vref	C (%)	ASH (%)	TOTAL ASH (ppm)	FIGURE 31 C (%)	FIGURE 32 TOTAL ASH (ppm)	FIGURE 33 ASH (%)	SOLIDS (%)	ASH (%)	FIGURE 35 SOLIDS (%)	FIGURE 36 ASH (%)
21/7/92	TABLET 58	HEADBOX	2.96	1613	0.58	21.60	1257.12	0.57	924.34	5.31	43.71	23.38	45.98	20.66
21/7/92	TABLET 58	SILO	1.68	2045	0.36	29.40	1070.16	0.35	814.82	2.81				
21/7/92	TABLET 58	HEADBOX	2.90	1668	0.55	19.40	1067.00	0.55	886.96	4.91	40.44	18.94	43.57	24.21
21/7/92	TABLET 58	SILO	1.80	2103	0.36	26.40	960.96	0.35	746.89	2.59				
21/7/92	TABLET 58	HEADBOX	2.88	1496	0.55	19.80	1085.04	0.60	1037.28	6.27	41.86	17.20	41.94	14.59
21/7/92	TABLET 58	SILO	1.66	1819	0.35	28.20	998.28	0.39	984.32	3.84				
22/7/92	TABLET 58	HEADBOX	2.85	1582	0.54	22.00	1181.40	0.57	968.56	5.55	29.78	8.71	34.95	10.16
22/7/92	TABLET 58	SILO	1.85	1796	0.42	28.60	1198.34	0.41	966.86	4.01				
22/7/92	TABLET 58	HEADBOX	2.80	1918	0.50	13.80	684.48	0.48	692.12	3.34	46.47	32.12	45.34	23.20
22/7/92	TABLET 58	SILO	1.66	2357	0.29	17.50	516.25	0.29	590.60	1.73				
23/7/92	BOND 80	HEADBOX	3.19	1510	0.57	27.30	1556.10	0.63	978.27	6.17	47.11	6.80	50.67	31.77
23/7/92	BOND 80	SILO	1.80	2110	0.33	48.10	1611.35	0.35	741.67	2.56				
27/7/92	TABLET 46	HEADBOX	2.02	2200	0.35	19.10	672.89	0.35	625.90	2.21	47.04	23.47	49.55	23.22
27/7/92	TABLET 46	SILO	1.07	2649	0.21	27.60	572.15	0.20	533.97	1.06				
27/7/92	TABLET 46	HEADBOX	2.09	2384	0.34	12.70	432.43	0.33	467.81	1.56	53.30	30.13	47.54	23.57
27/7/92	TABLET 46	SILO	1.19	2802	0.18	19.00	335.73	0.19	397.28	0.77				
28/7/92	SCRIPT 58	HEADBOX	2.46	1802	0.45	18.30	820.21	0.47	851.88	4.04	42.77	34.33	46.46	17.52
28/7/92	SCRIPT 58	SILO	1.32	2200	0.28	21.00	598.50	0.28	780.67	2.20				
28/7/92	SCRIPT 58	HEADBOX	2.90	1890	0.61	17.00	1043.97	0.50	696.83	3.48	62.80	63.90	59.12	33.31
28/7/92	SCRIPT 58	SILO	1.29	2590	0.25	16.50	418.77	0.23	516.39	1.17				
31/7/92	SCRIPT 58	HEADBOX	2.80	1990	0.47	11.60	545.20	0.47	631.18	2.96	55.80	31.42	50.69	17.07
31/7/92	SCRIPT 58	SILO	1.42	2450	0.23	18.00	415.44	0.26	581.63	1.49				
3/8/92	SCRIPT 58	HEADBOX	2.78	1880	0.50	11.00	550.00	0.49	728.07	3.56	4.60	-3.21	2.93	12.35
3/8/92	SCRIPT 58	SILO	3.07	1839	0.53	11.90	630.70	0.53	709.09	3.74				
3/8/92	SCRIPT 58	HEADBOX	2.70	1956	0.49	9.00	440.73	0.47	679.62	3.16	58.12	32.98	56.81	45.43
3/8/92	SCRIPT 58	SILO	1.38	2705	0.23	14.40	328.18	0.22	412.04	0.92				
3/8/92	SCRIPT 58	HEADBOX	2.72	1975	0.47	9.40	439.83	0.46	659.76	3.06	60.91	46.36	58.16	40.54
3/8/92	SCRIPT 58	SILO	1.30	2702	0.20	12.90	262.13	0.22	435.87	0.94				
3/8/92	SCRIPT 58	HEADBOX	2.70	1975	0.44	9.30	409.20	0.46	663.73	3.06	61.14	36.23	57.98	40.90
3/8/92	SCRIPT 58	SILO	1.30	2702	0.19	15.26	289.94	0.22	435.87	0.94				

DATE	PAPER GRADE	SAMPLE SOURCE	KAJAANI SIGNA Vcs	KAJAANI SIGNA Vref	LABORATORY MEASUREMEN C (%)	LABORATORY MEASUREMEN ASH (%)	LABORATORY MEASUREMEN TOTAL ASH (ppm)	CALCULATED VALUES FIGURE 31 C (%)	CALCULATED VALUES FIGURE 32 TOTAL ASH (ppm)	CALCULATED VALUES FIGURE 33 ASH (%)	RETENTION VALUES FROM LAB. DATA SOLIDS (%)	RETENTION VALUES FROM LAB. DATA ASH (%)	RETENTION VALUES FROM KAJAANI SIGNALS FIGURE 35 SOLIDS (%)	RETENTION VALUES FROM KAJAANI SIGNALS FIGURE 36 ASH (%)
6/8/92	MANUSC 60	HEADBOX	2.73	1838	0.54	12.20	658.80	0.49	772.77	3.81	61.67	36.22	52.87	24.87
6/8/92	MANUSC 60	SILO	1.35	2384	0.23	20.30	466.90	0.26	645.11	1.67				
6/8/92	MANUSC 60	HEADBOX	2.73	1763	0.51	13.11	668.61	0.51	835.72	4.27	50.59	23.68	50.65	19.06
6/8/92	MANUSC 60	SILO	1.35	2232	0.28	20.25	567.00	0.28	751.61	2.11				
6/8/92	MANUSC 60	HEADBOX	2.73	1640	0.52	14.17	736.84	0.54	938.96	5.11	48.08	14.81	51.55	27.78
6/8/92	MANUSC 60	SILO	1.43	2204	0.30	23.25	697.50	0.29	753.51	2.21				
7/8/92	TABLET 58	HEADBOX	2.72	1843	0.44	11.14	490.16	0.49	770.42	3.79	55.00	27.85	53.18	36.70
7/8/92	TABLET 58	SILO	1.46	2492	0.22	17.86	392.92	0.26	541.89	1.39				
7/8/92	TABLET 58	HEADBOX	2.67	1783	0.47	12.25	575.75	0.50	829.68	4.15	52.13	32.78	51.38	33.29
7/8/92	TABLET 58	SILO	1.47	2386	0.25	17.20	430.00	0.27	614.93	1.66				
7/8/92	TABLET 58	HEADBOX	2.73	1756	0.52	12.73	661.96	0.51	841.59	4.32	58.46	25.37	54.29	31.45
7/8/92	TABLET 58	SILO	1.37	2383	0.24	22.87	548.88	0.26	641.02	1.67				
10/8/92	TABLET 46	HEADBOX	2.30	2130	0.39	13.10	510.90	0.39	619.72	2.43	51.54	26.75	48.95	19.66
10/8/92	TABLET 46	SILO	1.22	2563	0.21	19.80	415.80	0.22	553.17	1.23				
10/8/92	TABLET 46	HEADBOX	2.30	2212	0.39	12.80	499.20	0.38	554.44	2.10	51.54	26.93	51.32	10.34
10/8/92	TABLET 46	SILO	1.10	2610	0.21	19.30	405.30	0.21	552.33	1.13				
10/8/92	TABLET 46	HEADBOX	2.23	2206	0.42	13.00	546.00	0.37	574.73	2.15	52.86	24.93	48.93	10.08
10/8/92	TABLET 46	SILO	1.12	2570	0.22	20.70	455.40	0.21	574.19	1.22				
10/8/92	TABLET 46	HEADBOX	2.24	2197	0.40	12.90	516.00	0.38	579.63	2.18	50.50	14.43	49.15	10.42
10/8/92	TABLET 46	SILO	1.12	2566	0.22	22.30	490.60	0.21	576.90	1.22				
11/8/92	TABLET 46	HEADBOX	2.30	1966	0.43	21.00	903.00	0.42	750.29	3.17	41.40	20.27	47.32	12.25
11/8/92	TABLET 46	SILO	1.16	2324	0.28	28.57	799.96	0.25	731.53	1.81				
11/8/92	TABLET 46	HEADBOX	2.40	1733	0.49	21.00	1029.00	0.49	918.37	4.46	37.55	16.14	38.93	13.28
11/8/92	TABLET 46	SILO	1.46	2010	0.34	28.20	958.80	0.33	884.94	2.91				
11/8/92	TABLET 46	HEADBOX	2.80	1632	0.55	19.00	1054.50	0.55	934.19	5.17	40.81	16.20	42.76	10.71
11/8/92	TABLET 46	SILO	1.53	1932	0.36	26.90	981.85	0.35	926.87	3.26				
11/8/92	TABLET 46	HEADBOX	2.53	1630	0.55	20.30	1116.50	0.53	980.12	5.16	39.45	13.51	41.86	13.12
11/8/92	TABLET 46	SILO	1.42	1935	0.37	29.00	1073.00	0.34	946.10	3.22				
12/8/92	TABLET 46	HEADBOX	2.60	2050	0.45	12.20	549.00	0.44	621.60	2.72	46.00	19.89	46.41	19.99
12/8/92	TABLET 46	SILO	1.48	2470	0.27	18.10	488.70	0.26	552.58	1.44				

DATE	PAPER GRADE	SAMPLE SOURCE	KAJAANI SIGNA		LABORATORY MEASUREMEN			CALCULATED VALUES			RETENTION VALUES			
											FROM LAB. DATA		FROM KAJAANI SIGNALS	
			Vcs	Vref	C (%)	ASH (%)	TOTAL ASH (ppm)	FIGURE 31 C (%)	FIGURE 32 TOTAL ASH (ppm)	FIGURE 33 ASH (%)	SOLIDS (%)	ASH (%)	FIGURE 35 SOLIDS (%)	FIGURE 36 ASH (%)
12/8/92	TABLET 46	HEADBOX	2.53	2056	0.41	14.60	598.60	0.43	631.11	2.71	49.51	33.85	45.57	23.08
12/8/92	TABLET 46	SILO	1.49	2485	0.23	19.13	439.99	0.26	539.38	1.40				
12/8/92	TABLET 46	HEADBOX	2.52	1934	0.42	11.95	501.90	0.45	733.00	3.31	46.43	26.84	48.35	34.04
12/8/92	TABLET 46	SILO	1.49	2488	0.25	16.32	408.00	0.26	537.23	1.39				
12/8/92	TABLET 46	HEADBOX	2.60	1473	0.53	22.90	1210.95	0.58	1098.38	6.41	37.28	9.70	38.99	14.65
12/8/92	TABLET 46	SILO	1.58	1760	0.37	32.97	1214.94	0.40	1041.65	4.12				
13/8/92	TABLET 58	HEADBOX	2.84	1838	0.46	10.68	495.55	0.50	752.45	3.80	44.95	23.20	47.81	32.67
13/8/92	TABLET 58	SILO	1.69	2385	0.28	14.90	422.86	0.29	562.91	1.65				
13/8/92	TABLET 58	HEADBOX	2.86	1838	0.47	10.05	468.23	0.51	748.75	3.79	46.78	28.72	49.74	33.97
13/8/92	TABLET 58	SILO	1.64	2420	0.28	13.46	370.82	0.28	549.35	1.55				
13/8/92	TABLET 58	HEADBOX	2.70	2065	0.46	11.89	546.94	0.44	588.46	2.62	49.72	32.72	46.94	17.72
13/8/92	TABLET 58	SILO	1.51	2480	0.26	15.91	408.89	0.26	537.97	1.41				
13/8/92	TABLET 58	HEADBOX	2.69	1926	0.45	11.43	511.15	0.47	706.64	3.32	49.24	25.71	48.64	34.51
13/8/92	TABLET 58	SILO	1.58	2488	0.25	16.73	421.93	0.27	514.23	1.38				
13/8/92	TABLET 58	HEADBOX	2.70	2017	0.50	10.90	545.00	0.45	628.60	2.85	50.88	25.78	45.58	20.25
13/8/92	TABLET 58	SILO	1.57	2433	0.27	16.47	449.47	0.27	556.98	1.53				
14/8/92	TABLET 70	HEADBOX	3.73	1554	0.63	10.47	659.82	0.67	854.97	5.74	42.55	35.52	45.89	40.54
14/8/92	TABLET 70	SILO	2.45	2158	0.40	11.75	472.70	0.40	564.90	2.28				
14/8/92	TABLET 70	HEADBOX	3.20	1746	0.60	12.55	751.74	0.56	767.52	4.32	55.23	37.74	51.91	42.87
14/8/92	TABLET 70	SILO	1.84	2438	0.30	17.45	520.01	0.30	487.21	1.47				
14/8/92	TABLET 70	HEADBOX	2.83	1979	0.49	12.58	619.94	0.47	634.53	3.01	47.48	36.58	49.17	37.30
14/8/92	TABLET 70	SILO	1.66	2560	0.29	15.19	436.86	0.27	442.03	1.18				
17/8/92	BANK 46	HEADBOX	2.28	2000	0.42	26.17	1097.31	0.41	727.24	3.01	42.00	22.92	44.25	15.72
17/8/92	BANK 46	SILO	1.29	2353	0.27	34.78	939.76	0.26	681.02	1.75				
17/8/92	BANK 46	HEADBOX	2.32	2069	0.44	17.00	746.30	0.41	664.13	2.69	42.23	-8.75	47.77	22.05
17/8/92	BANK 46	SILO	1.28	2509	0.28	32.00	901.76	0.24	575.18	1.35				
17/8/92	BANK 46	HEADBOX	2.32	2143	0.42	21.94	910.95	0.39	605.06	2.38	47.70	26.29	48.77	22.23
17/8/92	BANK 46	SILO	1.26	2592	0.24	30.92	746.10	0.22	522.81	1.17				
18/8/92	BANK 46	HEADBOX	2.32	2114	0.38	20.30	765.31	0.40	628.21	2.50	43.35	24.26	50.74	31.62
18/8/92	BANK 46	SILO	1.27	2654	0.24	27.14	644.03	0.22	477.27	1.04				

DATE	PAPER GRADE	SAMPLE SOURCE	KAJAANI SIGNA		LABORATORY MEASUREMEN			CALCULATED VALUES			RETENTION VALUES			
											FROM LAB. DATA		FROM KAJAANI SIGNALS	
			Vcs	Vref	C (%)	ASH (%)	TOTAL ASH (ppm)	FIGURE 31 C (%)	FIGURE 32 TOTAL ASH (ppm)	FIGURE 33 ASH (%)	SOLIDS (%)	ASH (%)	FIGURE 35 SOLIDS (%)	FIGURE 36 ASH (%)
18/8/92	BANK 46	HEADBOX	2.19	2160	0.36	18.12	653.04	0.38	619.71	2.33	48.43	15.39	49.01	29.24
18/8/92	BANK 46	SILO	1.23	2655	0.21	29.73	613.92	0.21	487.25	1.04				
18/8/92	BANK 46	HEADBOX	2.34	2136	0.39	22.02	853.94	0.40	606.36	2.40	47.36	27.50	49.93	24.06
18/8/92	BANK 46	SILO	1.25	2612	0.23	30.33	687.88	0.22	511.61	1.13				
18/8/92	BANK 46	HEADBOX	2.62	2094	0.49	17.28	841.19	0.43	581.04	2.51	63.26	41.90	56.97	30.29
18/8/92	BANK 46	SILO	1.22	2713	0.20	27.33	543.05	0.21	450.03	0.93				
18/8/92	BANK 46	HEADBOX	2.29	2204	0.38	18.93	719.15	0.38	563.02	2.14	47.31	29.86	48.46	22.40
18/8/92	BANK 46	SILO	1.26	2646	0.22	25.20	560.45	0.22	485.47	1.06				
19/8/92	BANK 46	HEADBOX	2.38	2210	0.36	18.05	653.41	0.39	538.26	2.09	48.54	30.09	50.06	30.59
19/8/92	BANK 46	SILO	1.32	2724	0.21	24.52	507.56	0.22	415.09	0.89				
19/8/92	BANK 46	HEADBOX	2.21	2285	0.36	18.68	670.89	0.36	516.98	1.86	50.35	29.58	47.57	28.01
19/8/92	BANK 46	SILO	1.28	2742	0.20	26.49	524.90	0.21	413.56	0.87				
19/8/92	BANK 46	HEADBOX	2.28	2233	0.39	20.00	780.00	0.37	542.20	2.03	52.23	37.42	48.32	22.17
19/8/92	BANK 46	SILO	1.26	2670	0.21	26.20	542.34	0.21	468.87	1.01				
24/8/92	TEXT 60	HEADBOX	2.69	1143	0.71	18.56	1317.76	0.74	1360.72	10.11	35.35	22.88	35.10	14.75
24/8/92	TEXT 60	SILO	1.78	1380	0.51	22.14	1129.14	0.54	1288.95	6.91				
24/8/92	TEXT 60	HEADBOX	2.77	1163	0.73	17.00	1241.00	0.74	1334.66	9.87	37.12	25.03	33.00	13.21
24/8/92	TEXT 60	SILO	1.87	1366	0.51	20.27	1033.77	0.55	1287.01	7.09				
27/8/92	TEXT 60	HEADBOX	2.47	1215	0.65	20.60	1339.00	0.68	1327.44	9.04	36.31	14.79	33.63	15.65
27/8/92	TEXT 60	SILO	1.72	1452	0.46	27.56	1267.76	0.50	1244.15	6.25				
27/8/92	TEXT 60	HEADBOX	2.54	1140	0.71	21.60	1533.60	0.73	1380.41	10.07	40.42	23.32	35.10	15.43
27/8/92	TEXT 60	SILO	1.70	1384	0.47	27.80	1306.60	0.53	1297.10	6.83				
27/8/92	TEXT 60	HEADBOX	2.49	1242	0.64	20.68	1323.52	0.67	1302.98	8.72	38.13	24.39	36.09	14.20
27/8/92	TEXT 60	SILO	1.57	1485	0.44	25.27	1111.88	0.48	1242.18	5.91				
27/8/92	TEXT 60	HEADBOX	2.54	1232	0.69	19.68	1357.92	0.68	1304.95	8.87	40.89	25.27	38.87	16.88
27/8/92	TEXT 60	SILO	1.59	1532	0.45	24.88	1127.56	0.46	1205.13	5.56				

LABORATORY ASH DETERMINATION ERROR

Figure 34
A sample of white water was taken from a paper machine and the original consistency and ash content measured as per TAPPI Standards.
A 5% solution of clay was prepared and then added to the sample to obtain different concentration of clay.

sample concentration (%)	clay added (%)	ash content detected (%)	total ash content (ppm)	theoretical total ash content (ppm)
0.92	0	4.90	450.8	450.8
0.96	5	10.34	992.6	930.8
1.06	10	14.36	1522.2	1510.8
1.12	15	17.95	2010.4	2130.8
1.17	20	21.15	2474.5	2790.8
1.22	25	24.34	2969.5	3500.8

APPENDIX 5

STREAMING CURRENT DETECTOR READINGS

STREAMING CURRENT DETECTOR READING VARIATION WITH A CHANGE IN pH AND CONDUCTIVITY

Figure 38

A sample of unrefined S/F stock was diluted to 1% with distilled water. The filtrate was recovered and divided into four different pH samples. The lower pH's were attained by addition of sulphuric acid. The charge of the water was measured using the streaming current detector. The conductivity of the sample was modified with potassium chlorate (KCL), the pH adjusted and the charge measured again.

SAMPLE CONDUCTIVITY (uS/cm)	STREAMING CURRENT DETECTOR READING (mA)			
	pH = 3.8	pH = 5.0	pH = 6.5	pH = 7.0
54		-7.20		
56				-8.48
80				-8.26
129				-7.71
154	-5.31			
230				-6.89
333				-6.13
404			-5.97	
465				-7.37
488		-3.67		
570				-4.78
688	-2.38			
896			-3.39	
974				-3.22
1008		-1.97		
1180	-1.48			
1487				-1.68
1498			-1.56	
1566		-0.99		
1660	-0.79			
1920				-0.69
2070		-0.42		
2110	-0.34			
2120			-0.51	
2430				-0.14
2510			-0.01	
2530	-0.02			
2570		-0.01		
2920				0.20
3020	0.19			
3090		0.24		
3100			0.32	
3400				0.45
3500	0.33			
3560			0.47	
3580		0.38		
3860				0.59
4000	0.38			
4050		0.48		
4200			0.62	
4380				0.67
4510	0.47	0.55		
4630			0.65	
4960			0.68	
4990	0.49			
5000				0.71

STREAMING CURRENT DETECTOR MEASUREMENTS HEADBOX & SILO CHARGE versus RETENTION

Figure 40 -
Samples from headbox and silo white waters, filtered and analysed.

date	sampling time	headbox			silo			retention (%)
		charge (mA)	conductivity (µS/cm)	pH	charge (mA)	conductivity (µS/cm)	pH	
07/05/92	8:15	-0.03	2240	4.9	0.07	2150	5.0	62.4
	9:15	-0.14	1920	4.9	-0.23	1880	5.0	61.1
	11:45	-0.15	1870	4.9	-0.13	1950	5.0	59.1
	13:30	-0.17	1840	4.8	-0.22	1800	5.0	60.0
	15:10	-0.04	2000	4.8	-0.06	1980	4.8	64.5
08/05/92	8:00	-0.12	1810	4.8	-0.16	1940	4.7	61.5
	9:00	-0.16	1990	4.7	-0.15	1840	4.8	63.1
	10:30	-0.15	1850	4.9	-0.15	1930	5.0	60.9
	11:30	-0.08	1860	5.2	-0.12	1880	5.0	59.8
	12:45	-0.10	1930	5.0	-0.15	1930	5.0	61.6
11/05/92	13:30	-0.01	2050	4.3	-0.03	2000	4.3	45.0
	14:30	0.03	2000	4.5	-0.01	2150	4.5	62.6
	15:30	0.10	2240	4.4	0.10	2260	4.5	51.6
12/05/92	10:20	-0.27	1490	5.0	-0.55	1400	5.0	60.0
	11:10	-0.54	1460	5.0	-0.59	1390	5.1	60.8
	13:30	-0.53	1460	5.2	-0.72	1400	5.4	60.5
	14:30	-0.54	1420	5.3	-0.68	1350	5.7	62.0
	15:30	-0.60	1420	5.3	-0.69	1330	5.7	60.1
13/05/92	9:00	-0.73	1310	5.8	-1.12	1200	6.3	63.9
	11:00	-0.47	1340	4.9	-0.75	1300	5.8	65.5
	12:00	-0.55	1320	5.1	-1.01	1200	5.8	64.8
	13:25	-0.57	1270	5.1	-0.93	1180	6.1	62.5
	14:25	-0.18	1490	4.3	-0.22	1270	4.5	65.5
15/05/92	11:00	-0.11	1760	4.6	-0.13	1800	4.8	55.4
	11:45	-0.07	1700	4.8	-0.15	1760	4.8	59.1
	13:00	-0.08	1800	4.8	-0.10	1700	4.8	53.2
	14:25	-0.05	1800	4.9	-0.13	1840	5.0	56.5
	15:30	-0.03	1840	5.0	-0.11	1760	5.2	54.5
18/05/92	9:30	0.10	2040	4.8	0.04	2200	4.8	58.2
	10:45	0.14	2110	4.9	0.05	2320	4.9	55.1
	13:15	0.08	2200	4.9	0.08	2340	4.9	52.2
19/05/92	8:30	0.03	2000	4.9	0.01	1800	4.9	46.8
	9:30	0.07	2080	4.8	-0.02	1800	4.8	48.8
	10:30	0.05	2030	4.8	-0.02	1900	4.8	47.6
	11:30	0.00	2100	4.8	-0.02	1950	4.9	50.0
	13:30	0.03	2000	4.8	-0.04	1940	4.8	55.5
	15:50	0.16	2050	4.7	0.13	1960	4.7	54.8
20/05/92	9:00	0.05	2000	4.7	0.00	1980	4.7	58.1
	10:30	0.07	2040	4.6	0.03	2040	4.5	55.3
	14:00	-0.02	1980	4.3	-0.01	1930	4.3	59.1
	15:30	-0.03	1880	4.3	-0.07	1800	4.3	60.0
22/05/92	9:00	-0.30	1430	5.0	-0.30	1400	5.1	62.2
	10:50	-0.31	1490	5.2	-0.39	1500	5.0	62.0
	14:00	-0.30	1490	5.3	-0.36	1400	5.2	61.1
	15:00	-0.29	1570	5.3	-0.33	1470	5.1	57.5

APPENDIX 6

BRIGHTNESS MEASUREMENTS

TMP PULP BRIGHTNESS VARIATION AT THE DECKERS

Figure 44
Grab samples of TMP pulp taken after the decker chest in mills 1 & 2 were analysed for brightness as per TAPPI Standards.

GRAB SAM	PULP BRIGHTNESS ISO F11 AFTER DECKER CHEST	
	MILL 1	MILL 2
1	59.7	58.0
2	60.0	61.7
3	61.4	61.9
4	61.0	62.0
5	63.2	59.5
6	59.5	59.0
7	61.6	59.6
8	62.1	59.7
9	61.4	61.7
10	59.6	61.2
11	59.1	60.8
12	60.5	61.5
13	60.6	62.2
14	60.2	62.4
15	60.4	61.0
16	60.0	58.6
17	58.7	58.7
18	59.3	59.0
19	58.7	62.0
20	58.9	61.6
21	63.4	60.0
22	61.6	59.0
23	59.7	59.2
24	61.2	63.4
25	60.0	60.7
26	62.7	60.5
27	60.5	62.0
28	62.0	60.6
29	58.2	59.2
30	59.6	60.0
31	60.9	
32	62.0	

Average pulp brightness:
60.60
Standard deviation:
1.33

PAPER BRIGHTNESS VARIATION OF NEWSPRINT PAPERMACHINES 4 & 5

Figure 45
Paper samples off the machines analysed for brightness as per TAPPI standards.
Paper machines running Newsprint Shade 3.

PAPER SAMPLES	PAPER BRIGHTNESS ISO F11 AT THE PAPER MACHINES	
	MACHINE 4	MACHINE 5
1	58.9	58.2
2	58.8	58.7
3	58.5	58.5
4	58.8	58.2
5	58.9	60.0
6	59.4	60.2
7	59.9	60.4
8	58	60.8
9	58.4	59.6
10	58.7	59.8
11	60.5	59.0
12	60	58.9
13	59.8	59.8
14	60.3	59.9
15	59.6	58.4
16	59.7	58.6
17	60.2	59.0
18	60.4	59.2
19	60	59.4
20	60.5	59.6
21	60.1	59.5
22	59.6	59.8
23	58.4	59.8
24	58.7	59.9
25	58.9	58.6
26	59	59.1
27	59.5	59.8
28	59.8	61.0
29	61.7	61.3
30	61.1	61.3
31	61.4	61.0
32	61.7	
33	61.5	
34	62	
35	61.9	
36	62.5	

Average paper brightness:
59.70
Standard deviation:
1.05

TMP PULP BRIGHTNESS VARIATION AT THE DECKERS AFTER BRIGHTNESS SENSOR INSTALLATION

Figure 49
Grab samples of TMP pulp taken after the decker chest in mills 1 & 2 were analysed for brightness as per TAPPI Standards. The brightness sensors were installed and the addition of sodium hydrosulphite was automatically controlled.

GRAB SAM	PULP BRIGHTNESS ISO F11 AFTER DECKER CHEST	
	MILL 1	MILL 2
1	59.6	59.8
2	60.3	61.9
3	59.9	60.9
4	59.2	59.9
5	60.3	60.5
6	61.3	59.4
7	60.9	59.2
8	60.6	59.4
9	60.2	59.7
10	60.0	59.4
11	61.0	60.6
12	60.8	62.3
13	61.1	60.6
14	61.6	60.7
15	61.5	60.4
16	61.6	60.0
17	61.9	59.8
18	61.8	60.3
19	59.4	60.5
20	59.1	59.4
21	59.2	59.0
22	59.5	59.1
23	60.0	61.0
24	60.5	60.3
25	60.9	
26	60.5	
27	60.0	
28	59.4	
29	60.0	
30	60.1	
31	60.9	
32	60.6	

Average pulp brightness:
60.42
Standard deviation:
0.70

PAPER BRIGHTNESS VARIATION OF NEWSPRINT PAPERMACHINES 4 & 5 AFTER BRIGHTNESS SENSOR INSTALLATION

Figure 50
Paper samples off the machines analysed for brightness as per TAPPI standards. Paper machines running Newsprint Shade 3 and TMP pulp brigtness automatically controlled using the brightness sensors.

PAPER SAMPLE	PAPER BRIGHTNESS ISO F11 AT THE PAPER MACHINES	
	MACHINE 4	MACHINE 5
1	59.6	60.4
2	59.5	60.9
3	59.5	60.3
4	60.0	60.1
5	60.2	60.3
6	60.2	60.1
7	59.4	60.2
8	59.8	60.1
9	61	60.3
10	61	60.7
11	61.1	60.2
12	61.2	60.8
13	61.1	60.5
14	60.4	60.1
15	60.3	59.8
16	60.5	59.6
17	61.2	59.9
18	60.8	60.4
19	60.6	60.2
20	60.6	60.0
21	60.6	60.3
22	60.4	60.1
23	60.3	60.8
24	60.5	60.5
25	60.6	59.8
26	60.6	60.2
27	60.5	60.3
28	60.8	59.7
29	60.8	59.8
30	61	60.2
31	60.8	60.3
32	61	60.7
33	61.1	60.5
34	61.1	60.3
35	61.1	60.5
36	60	60.5
37	60.4	60.6
38	60.6	60.4
39	60.6	60.8
40	60.5	59.9
41	60.3	59.8

Average paper brightness:
60.44
Standard deviation
20.96

PAPER SAMPLES	PAPER BRIGHTNESS ISO F11 AT THE PAPER MACHINES	
	MACHINE 4	MACHINE 5
42	60.4	60.0
43	60.4	60.7
44	60	60.3
45	60.4	60.8
46	60	
47	60.5	
48	60.4	
49	61	
50	61	
51	61	
52	61	
53	60	
54	59.8	
55	59.8	
56	59.9	
57	59.9	
58	60.6	
59	61	
60	61.2	
61	61.2	
62	61.2	
63	61.2	
64	61.5	
65	61	
66	60.5	
67	59.6	
68	59.6	
69	60	
70	61.6	
71	61	
72	61.1	

PAPER BRIGHTNESS VARIATION
BLEACHED GROUNDWOOD PULP

FIGURE 53
Sample of paper taken off paper machine 3 making Text 60 g/m2 with a furnish of Bleached Groundwood and chemical pulps.
Average brightness of making: 72.5
Standard deviation of making: 1.38

PAPER SAMPLES	PAPER BRIGHTNESS ISO F11
1	76.0
2	75.5
3	75.7
4	73.9
5	73.0
6	73.5
7	74.1
8	73.5
9	73.2
10	73.8
11	73.5
12	72.1
13	72.8
14	71.7
15	72.7
16	73.6
17	74.1
18	73.5
19	73.2
20	73.8
21	73.5
22	72.1
23	72.8
24	71.8
25	72.7
26	73.5
27	74.0
28	74.3
29	73.8
30	73.5
31	73.3
32	73.2
33	71.5
34	71.3
35	71.4
36	73.1
37	73.3
38	73.4
39	72.4
40	72.1
41	72.5

PAPER SAMPLES	PAPER BRIGHTNESS ISO F11
42	71.9
43	72.1
44	71.6
45	71.9
46	73.5
47	73.6
48	75.4
49	75.4
50	75.0
51	75.5
52	74.8
53	74.2
54	73.4
55	73.7
56	73.2
57	73.9
58	73.8
59	73.2
60	73.0
61	72.6
62	73.3
63	72.8
64	72.0
65	71.2
66	71.9
67	72.2
68	73.1
69	73.3
70	72.9
71	73.3
72	73.0
73	73.3
74	73.4
75	73.5
76	73.4
77	72.9
78	73.4
79	73.3
80	73.3
81	73.3
82	73.2

PAPER SAMPLES	PAPER BRIGHTNESS ISO F11
83	73.3
84	73.4
85	72.9
86	71.8
87	71.0
88	72.2
89	71.7
90	73.0
91	72.9
92	72.9
93	73.2
94	73.0
95	73.4
96	75.0
97	74.5
98	73.0
99	71.5
100	72.9
101	72.6
102	73.9
103	72.7
104	71.7
105	72.5
106	72.9
107	71.7
108	71.8
109	72.4
110	72.2
111	71.7
112	71.5
113	72.1
114	69.8
115	70.9
116	70.9
117	69.6
118	68.8
119	70.4
120	69.5
121	72.4
122	72.8
123	72.0
124	73.0
125	70.8
126	69.6
127	71.3
128	72.2
129	72.4
130	72.6
131	70.4
132	70.1
133	72.9

PAPER SAMPLES	PAPER BRIGHTNESS ISO F11
134	73.9
135	72.4
136	71.3
137	70.3
138	69.5
139	70.4
140	72.3
141	72.9
142	73.2
143	73.1
144	73.5
145	71.5
146	71.3
147	73.2
148	73.2
149	73.2
150	73.1
151	70.7
152	71.3
153	73.0
154	73.6
155	73.5
156	73.2
157	72.4
158	71.3
159	69.0
160	68.9
161	70.8
162	72.6
163	73.2
164	73.5
165	73.4
166	72.0
167	70.7
168	72.4
169	72.8
170	72.6
171	72.4
172	71.8
173	69.5
174	68.8
175	70.6
176	70.4
177	71.3
178	71.6
179	71.5
180	69.5
181	69.5
182	71.4
183	72.0
184	72.8